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MONTHLY WEATHER REVIEW

VOLUME 81 NUMBER 1

JANUARY 1953

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U. S. DEPARTMENT OF COMMERCE • WEATHER BUREAU

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MONTHLY WEATHER REVIEW

First published in 1872, the Monthly Weather Review serves as a medium of publication for technical contributions in the field of meteorology, principally in the branches of synoptic and applied meteorology. In addition each issue contains an article descriptive of the atmospheric circulation during the month over the Northern Hemisphere with particular reference to the effect on weather in the United States. A second article deals with some noteworthy feature of the month's weather. Illustrated. Annual subscription Domestic, $3.50; Foreign, $4.50. Subscription to the *Review* does not include the *Supplements* which have been issued irregularly and are for sale separately.

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(Continued on inside back cover)

The Weather Bureau desires that the *Monthly Weather Review* serve as a medium of publication for original contributions within its field, but the publication of a contribution is not to be construed as official approval of the views expressed.

The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C. Requests for a limited number of reprints of the more important contributions can be granted; such requests should be made by the author on the first page of his manuscript.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 11, 1952

Science QC 983 A27 81 1953

DEPARTMENT OF COMMERCE
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MONTHLY WEATHER REVIEW

Editor, JAMES E. CASKEY, JR.

Volume 81
Number 1

JANUARY 1953

Closed March 15, 1953
Issued April 15, 1953

AN EXTRAORDINARY RAINFALL CENTERED AT HALLETT, OKLA.

GEORGE A. LOTT

Hydrologic Services Division, U. S. Weather Bureau,[1] Washington, D. C.

[Manuscript received May 13, 1952; revised manuscript received August 13, 1952]

INTRODUCTION

The Hallett, Okla., storm of September 4, 1940, was the most intense rainstorm considering depth, duration, and area ever observed in Oklahoma. It has been exceeded by but few heavy rainstorms of record in the United States. Official rainfall measurements of up to 15½ inches and bucket survey totals of 24 inches were recorded. Almost all rain fell within a 9-hour period. Because of its intensity property damage was very great [1]. Figure 1 shows a generalized isohyetal pattern for the total storm period, and figure 2 the depth-duration-area curves.

The storm is one of a group in which little in the way of clues to the intense rainfall can be derived easily from the surface weather map. No surface low, pronounced pressure fall, or surface temperature discontinuity is

[1] In cooperation with the Corps of Engineers, Department of the Army.

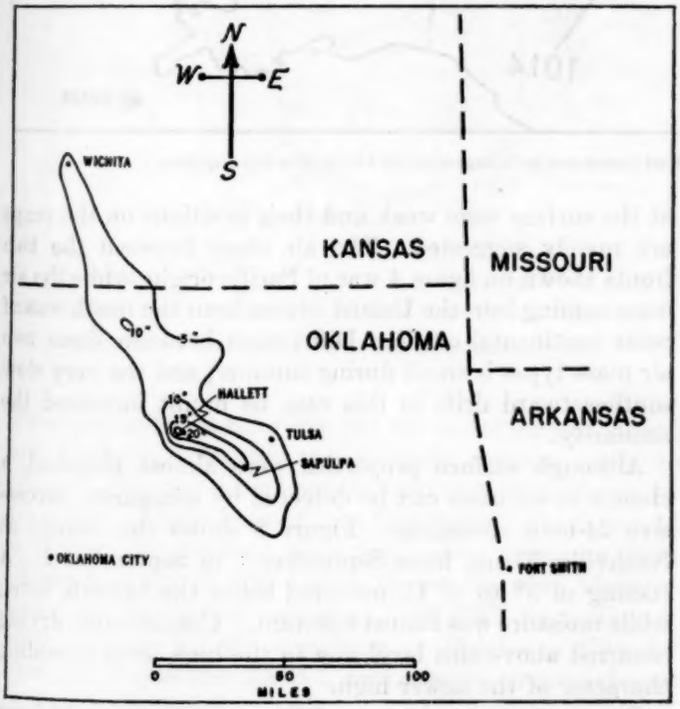

FIGURE 1.—Total rainfall for the Hallett, Okla., storm. Almost all rain fell between 0200 and 1100 CST, September 4, 1940. Note the orientation of the isohyetal pattern. The rain area progressed in time from the northwest to the southeast.

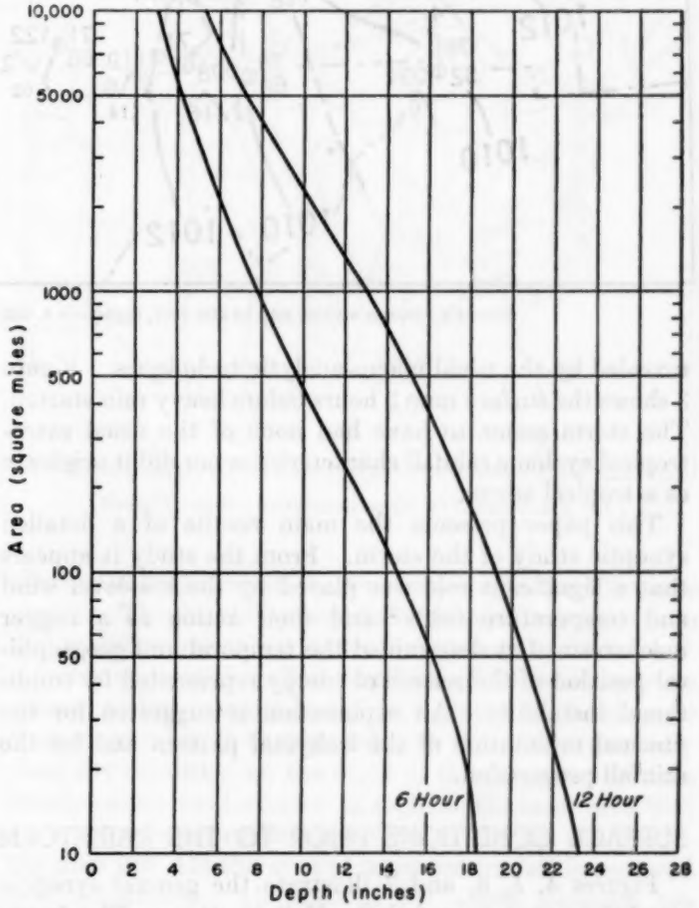

FIGURE 2.—Depth-duration-area curves for the Hallett, Okla., storm, September 4, 1940.

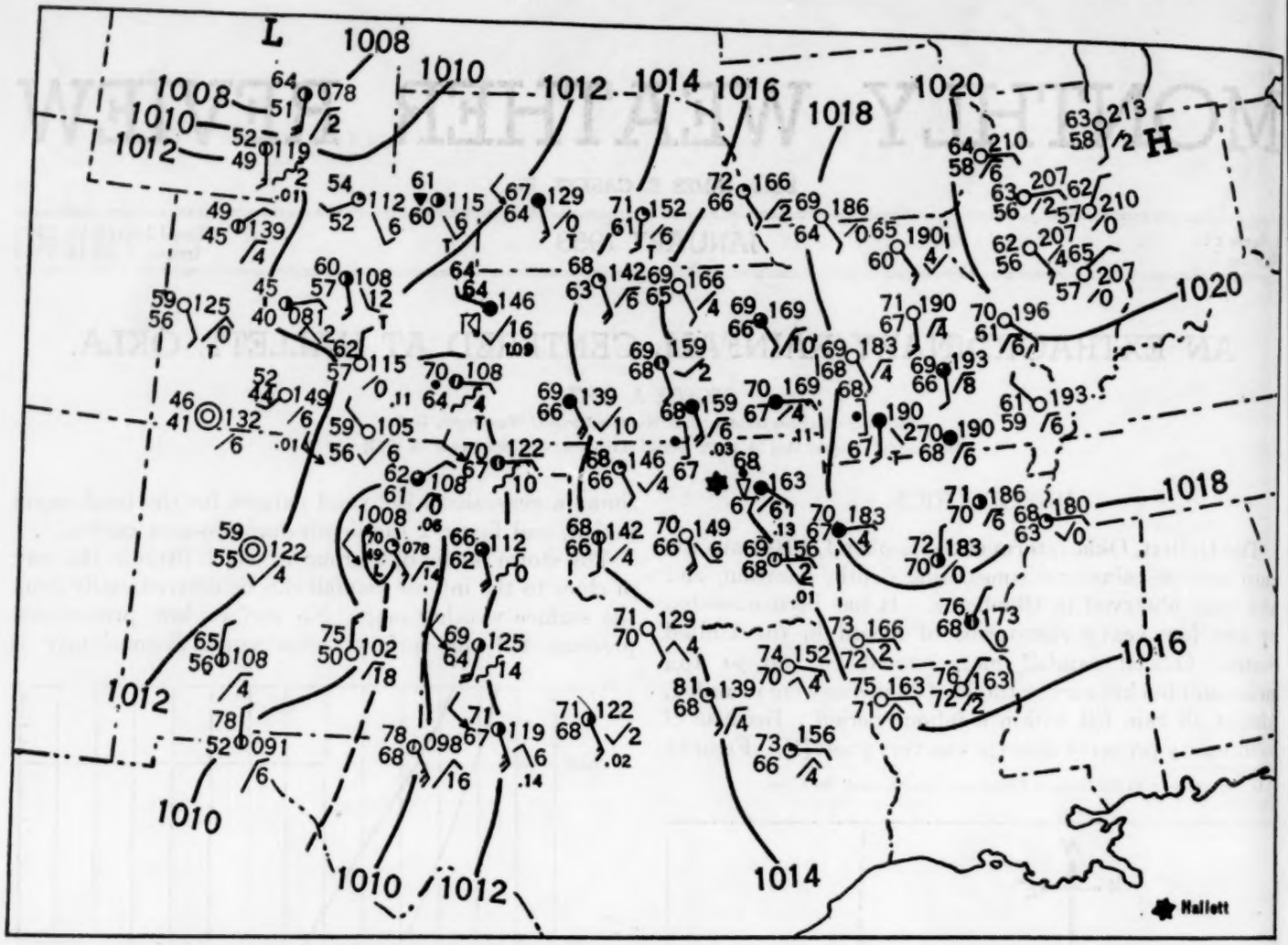

FIGURE 3.—Surface weather map for 0130 EST, September 4, 1940. Most intense rain in Oklahoma started 3 hours after this map time.

revealed by the usual macro-analytic techniques. Figure 3 shows the surface map 3 hours before heavy rain started. The storm seems to have had none of the usual extra-tropical cyclonic rainfall characteristics nor did it originate as a tropical storm.

This paper presents the main results of a detailed synoptic study of the storm. From the study it appears that a significant role was played by the low-level wind and temperature fields[2] and their action as a trigger mechanism that determined the temporal and geographical position of the release of energy represented by conditional instability. An explanation is suggested for the unusual orientation of the isohyetal pattern and for the rainfall progression.

SURFACE CONDITIONS PRIOR TO THE RAINSTORM

Figures 4, 5, 6, and 7 illustrate the general synoptic conditions that preceded the Hallett storm. The fronts at the surface were weak and their positions on the maps are merely suggested. The air mass between the two fronts shown on figure 4 was of Pacific origin, while the air mass coming into the United States from the north was of polar continental origin. Differences between these two air mass types is small during summer, and the very slow southeastward drift in this case no doubt increased the similarity.

Although surface properties were almost identical, a change in air mass can be detected by comparing successive 24-hour soundings. Figure 8 shows the change at Nashville, Tenn., from September 1 to September 2. A cooling of 3° to 4° C. occurred below the 840-mb. level, while moisture was almost constant. Considerable drying occurred above this level due to the high level subsiding character of the newer high.

Figures 9, 10, and 11 are 500-meter charts at 24-hour intervals which show more clearly the influx of cooler air at the lower levels. A rather pronounced trough is seen on figure 9 just south of Memphis with cold air advection indicated over the area from western Tennessee northward.

[2] This result is in accord with findings of Gilman [2] who has given a detailed discussion of the role of the wind and temperature fields (advection) in the development of atmospheric disturbances.

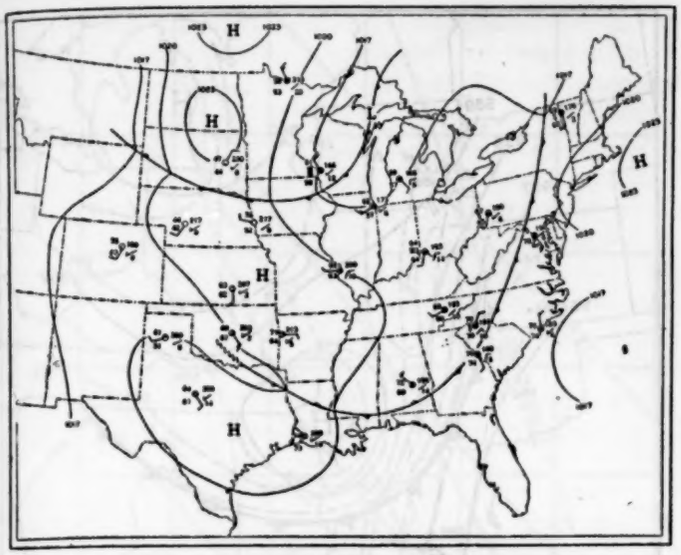

FIGURE 4.—Surface weather map for 0730 EST, August 31, 1940. This map and those in figures 5, 6, and 7 show the synoptic conditions which led up to the storm.

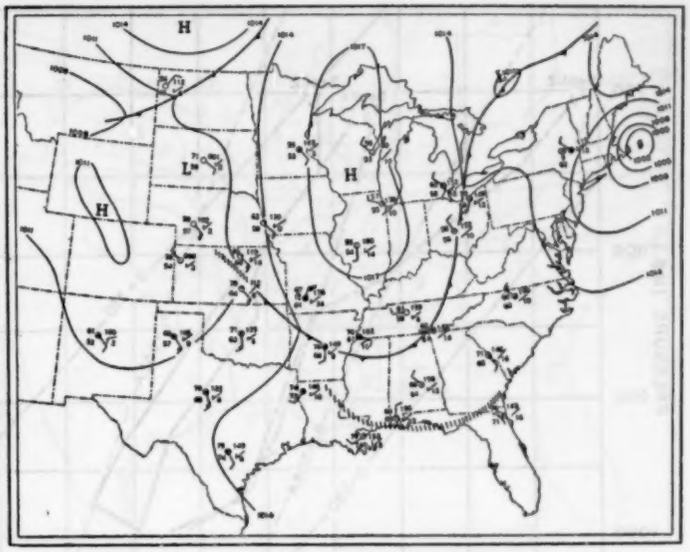

FIGURE 6.—Surface weather map for 0730 EST, September 2, 1940.

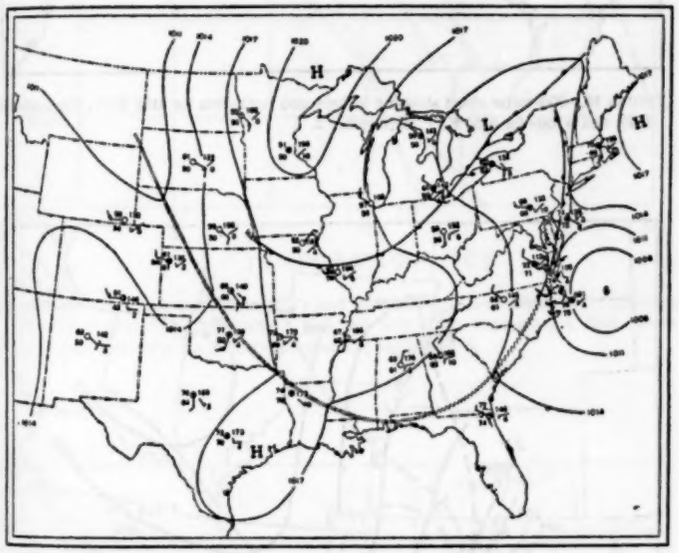

FIGURE 5.—Surface weather map for 0730 EST, September 1, 1940.

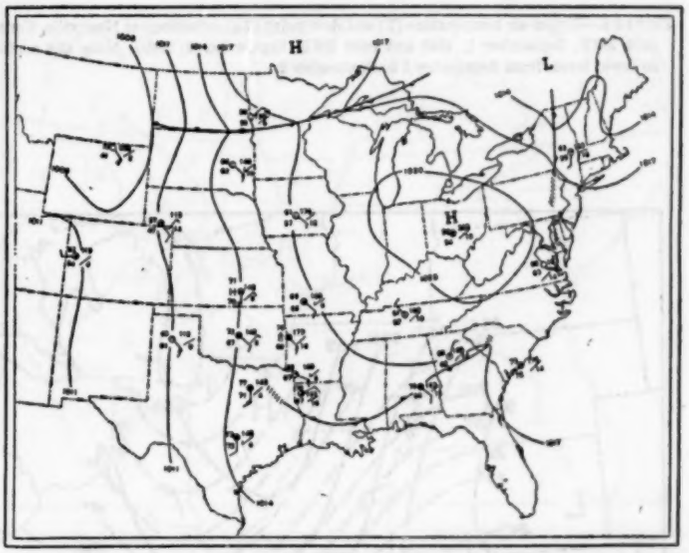

FIGURE 7.—Surface weather map for 0730 EST, September 3, 1940.

Twenty-four hours later (fig. 10) the cooler air had moved into southern Arkansas and adjacent regions, while on figure 11, the map a few hours before storm time, the cooler air is seen to have moved into Oklahoma. On figure 11 is plotted the 48-hour trajectory going upstream from Oklahoma City at 500 meters (based on wind observations) for the period ending at 0100 EST September 4, 1940. Figure 12, the soundings at Oklahoma City for 0100 EST September 3 and 4, indicates the air mass change in the lowest layers.

Twenty-four-hour surface temperature-change maps for the 4 days prior to the storm are shown in figures 13, 14, and 15. Movement of the forward portion of the cooler air mass can be traced by these temperature changes. The track of the center of temperature fall follows rather closely the trajectory of the air computed on the 500 meter charts. The possibility that these changes may have been due to differences solely in cloud cover may be discounted. At some stations this effect may have distorted the picture somewhat but in most instances, notably in the changes from September 2 to September 3 (fig. 14) a generally clear sky condition on the night of the 2d gave way to a cloudy condition the following night in the same area that surface temperatures lowered 4° to 8° F. On the following map (fig. 15) the area of temperature fall is centered over Oklahoma. All stations for which changes are plotted, with the exception of Oklahoma City, reported some cloudiness on both nights. Oklahoma City itself reported middle broken clouds at 0130 EST on the 3d while clear conditions prevailed at 0130 EST on the 4th.

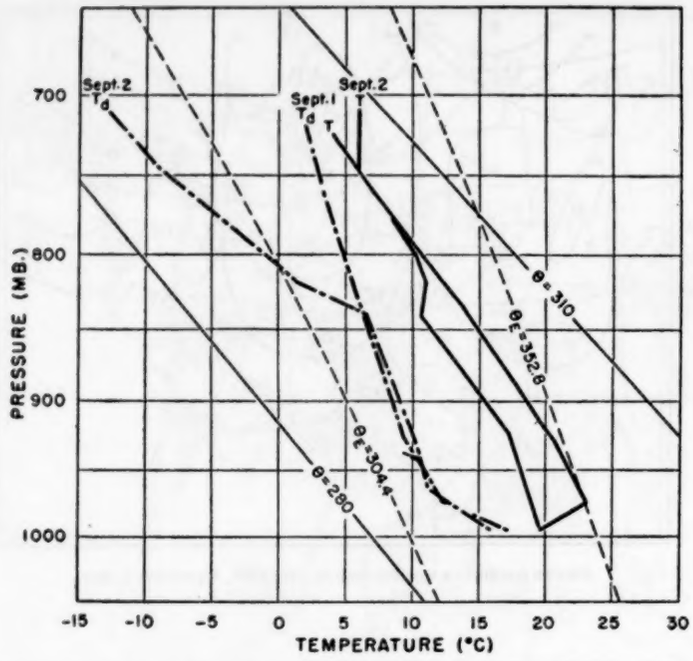

FIGURE 8.—Upper-air temperature (T) and dew point (T_d) soundings at Nashville, Tenn.: 0100 EST, September 1, 1940 and 0100 EST, September 2, 1940. Note the cooling in lower levels from September 1 to September 2.

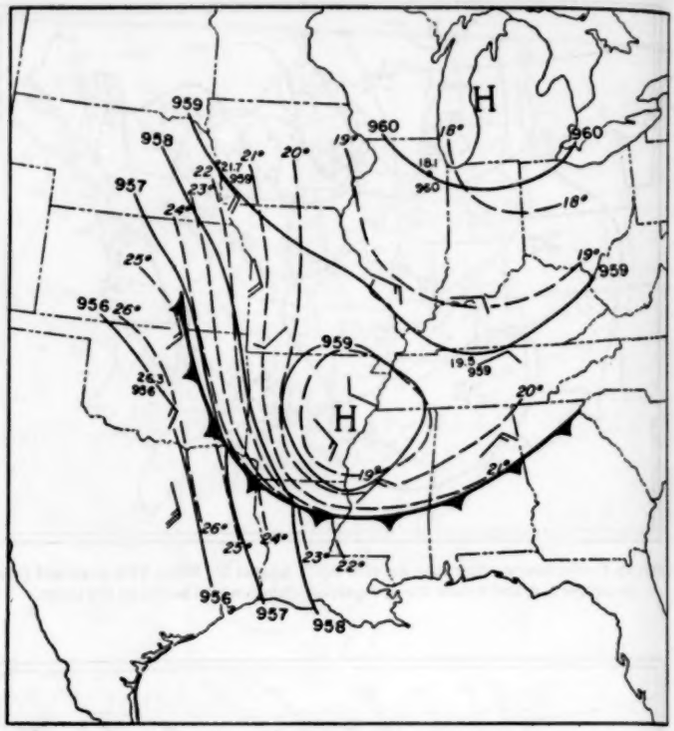

FIGURE 10.—500-meter chart showing isobars and isotherms for 0100 EST, September 1, 1940, and winds for 2300 EST, September 2.

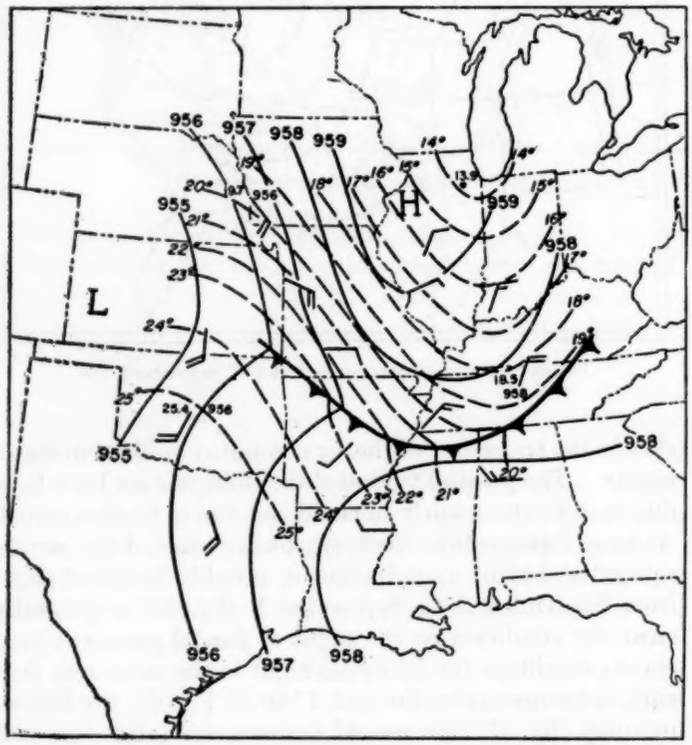

FIGURE 9.—500-meter chart showing isobars (solid lines, labeled in millibars) and isotherms (dashed lines, °C) for 0100 EST, September 2, 1940, and winds for 2300 EST, September 1. Compare with figures 10 and 11 to see movement of cooler air from the east.

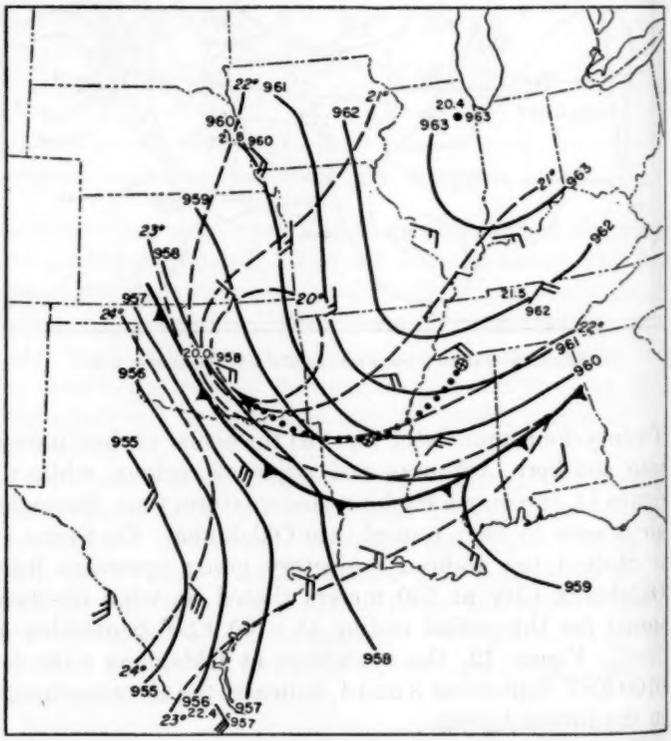

FIGURE 11.—500-meter chart showing isobars and isotherms for 0100 EST, September 4, 1940, and winds for 2300 EST, September 3. The dotted line is the upstream air trajectory from Oklahoma City based on wind observations for the 48-hour period ending at this map time.

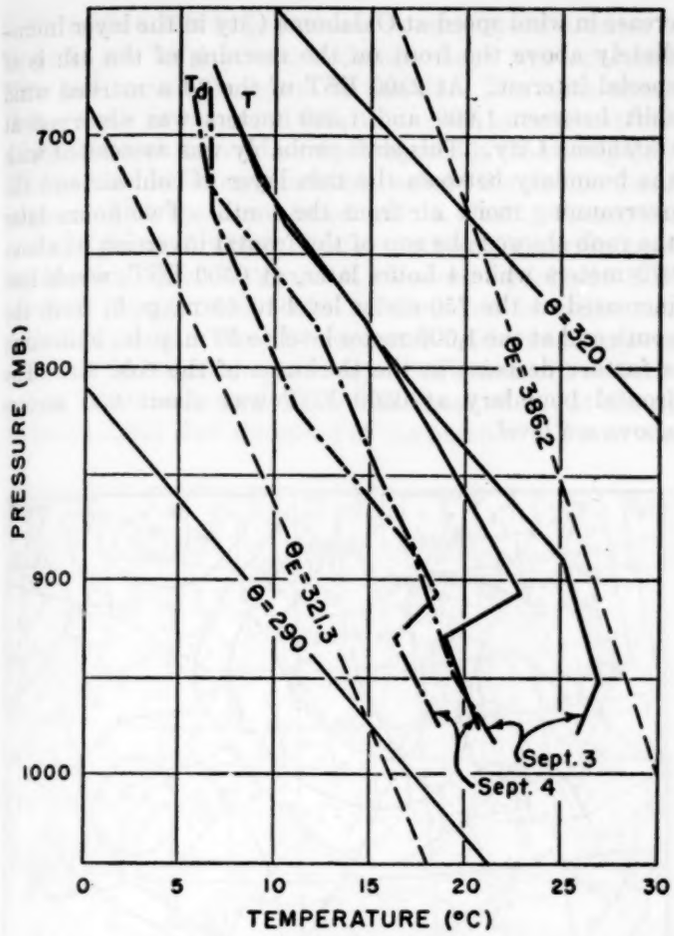

FIGURE 12.—Upper-air temperature (T) and dew point (T_d) soundings at Oklahoma City, Okla.: 0100 EST, September 3, 1940 and 0100 EST, September 4, 1940. Note the cooling in lower levels from September 3 to September 4.

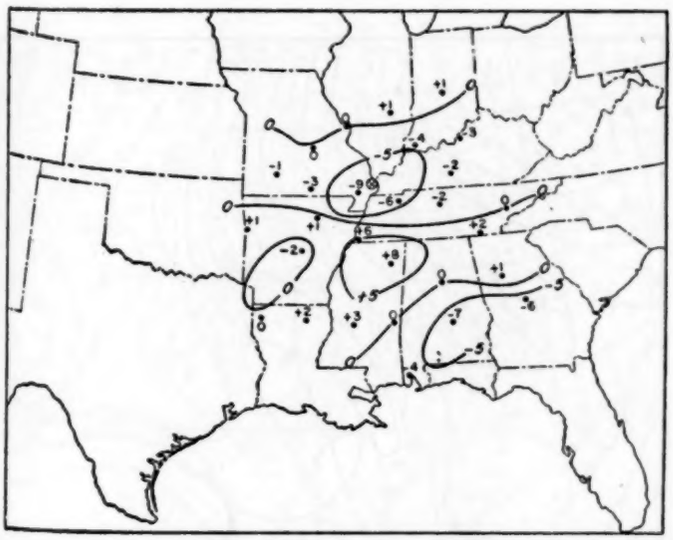

FIGURE 13.—24-hour surface temperature change (° F.) from 0130 EST, September 1 to 0130 EST, September 2, 1940. Compare with figures 14 and 15.

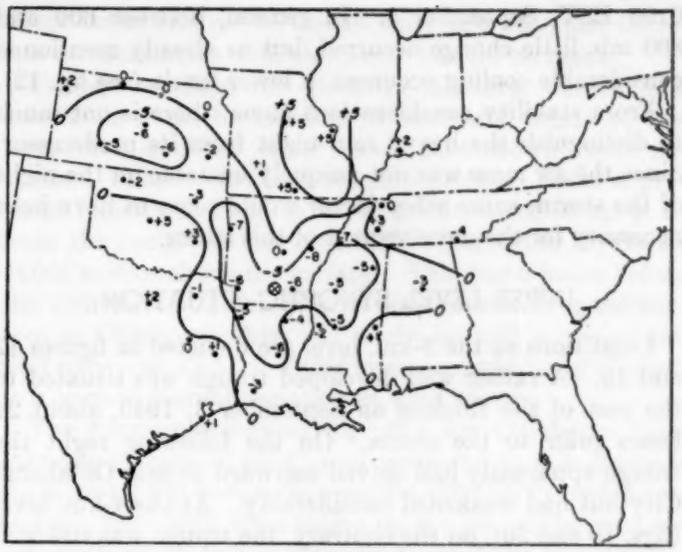

FIGURE 14.—24-hour surface temperature change (° F.) from 0130 EST, September 2 to 0130 EST, September 3, 1940.

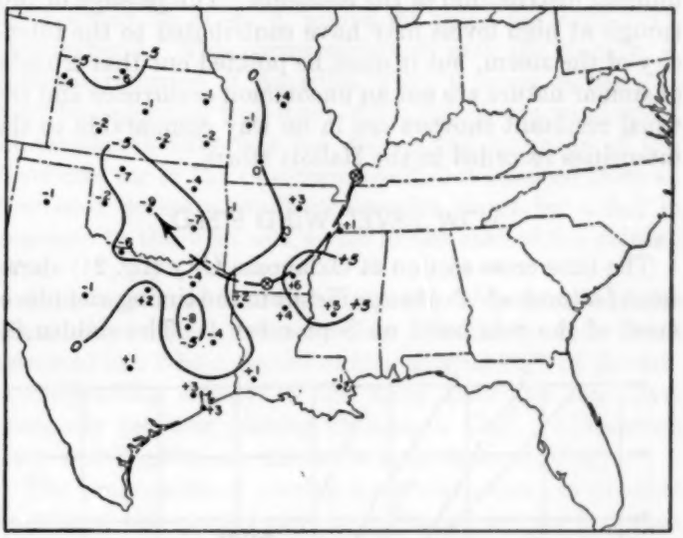

FIGURE 15.—24-hour surface temperature change (° F.) from 0100 EST, September 3 to 0100 EST, September 4, 1940. The track of the center of 24-hour temperature fall for the period covered by figures 13, 14, and 15 is shown by dashed arrow.

UPPER AIR SOUNDINGS AT OKLAHOMA CITY

The upper air sounding at Oklahoma City at 0100 EST, September 3, 1940 (lower levels only shown in fig. 12), revealed the presence of very moist air up to the 300-mb. level. Conditional instability of the real latent type was present to a noticeable degree. No large-scale rains occurred on that night.

On the following night (0100 EST, September 4) however, the Oklahoma City sounding (fig. 16) showed that drier air had moved in aloft over the moist southerly current. Above the 530-mb. level convectively stable air was then present, but real latent conditional instability was present below this level to about the same degree as at

0100 EST, September 3. In general, between 600 and 800 mb. little change occurred, but as already mentioned considerable cooling occurred in lower levels (see fig. 12).

From stability considerations alone, there is not much to distinguish the heavy rain night from its predecessor. Since the air mass was not uniquely unstable on the night of the storm, some other factor would seem to have been necessary for the development of this storm.

UPPER LEVEL SYNOPTIC SITUATION

Conditions at the 3-km. level are depicted in figures 17 and 18. A rather well developed trough was situated to the east of the Rockies on September 3, 1940, about 24 hours prior to the storm. On the following night the trough apparently had moved eastward to near Oklahoma City but had weakened considerably. At the 4-km. level (figs. 19 and 20), on the contrary, the trough was still well marked on the night of the storm.

At neither 3 nor 4 km. was the trough distinguished by unusual distribution of the elements. The passage of this trough at high levels may have contributed to the intensity of the storm, but it must be pointed out that troughs of similar nature are not an uncommon occurrence and the usual resultant showers are in no way comparable to the intensities recorded in the Hallett storm.

LOW LEVEL WIND FIELD

The time cross section at Oklahoma City (fig. 21) shows some features which are significant in the timing and placement of the rain burst on September 4. The sudden increase in wind speed at Oklahoma City in the layer immediately above the front on the morning of the 4th is of special interest. At 2300 EST of the 3d a marked wind shift between 1,000 and 1,500 meters was observed at Oklahoma City. This shift probably was associated with the boundary between the thin layer of cold air and the overrunning moist air from the south. Two hours later the raob showed the top of the frontal inversion at about 970 meters while 4 hours later, at 0500 EST, winds had increased at the 750-meter level to 45 m. p. h. from the south and at the 1,000-meter level to 50 m. p. h., indicating a further decrease in the thickness of the cold air. The frontal boundary at 0500 EST was about 650 meters above sea level.

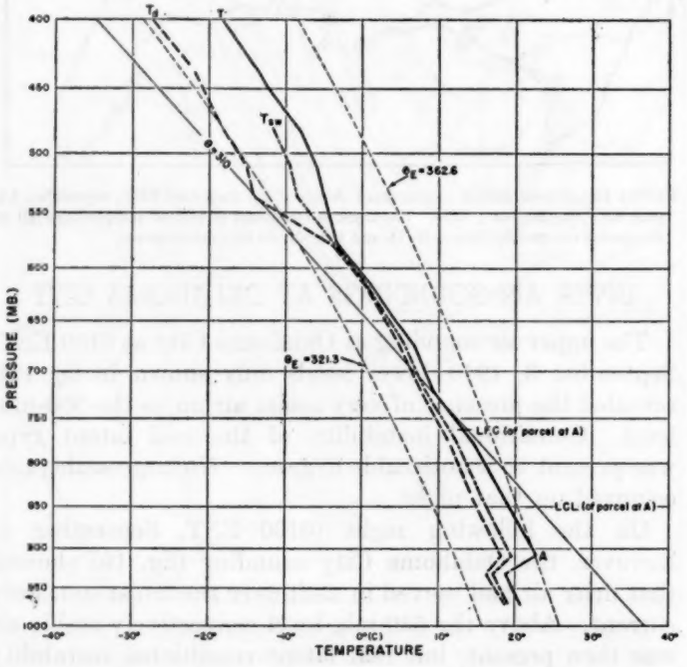

FIGURE 16.—Upper air temperature (T), dew point (T_d) and pseudo-wet bulb temperature (T_{sw}) sounding for Oklahoma City, 0100 EST, September 4, 1940. The lifting condensation level (LCL) and level of free convection (LFC) are indicated. Drier air has moved over the area above the 530-mb. level.

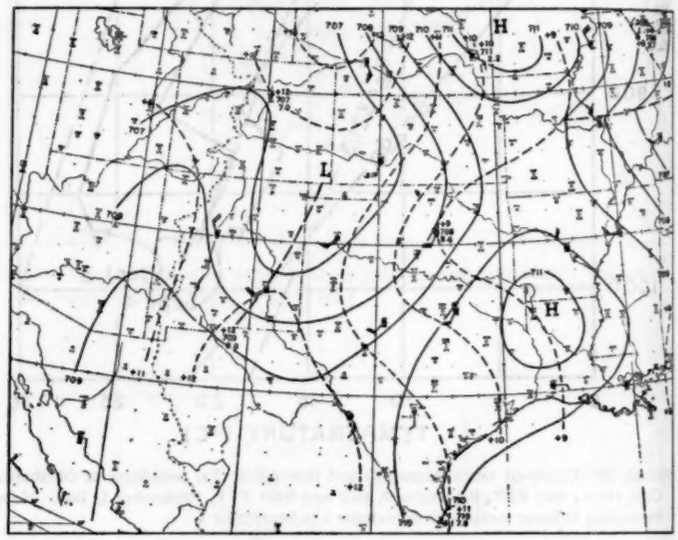

FIGURE 17.—3-km. chart showing isobars (solid lines, labeled in mb.) and isotherms (dashed lines, ° C.) for 0100 EST, and winds for 0500 EST, September 3, 1940.

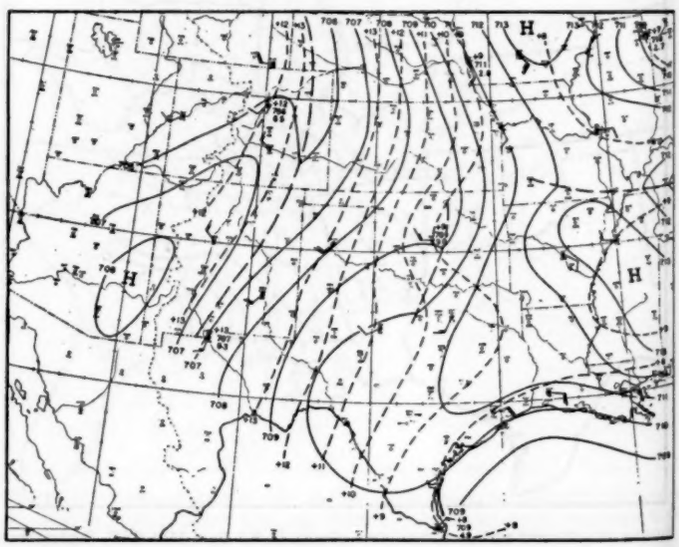

FIGURE 18.—3-km. chart showing isobars and isotherms for 0100 EST and winds for 0500 EST, September 4, 1940. Trough to east of Rockies on figure 17 has moved eastward but weakened considerably.

To explain this large increase in wind speed a series of 24-hour sea level pressure change maps was analyzed. Two can be seen in figures 22 and 23. The series shows that a weak pressure fall area was centered near 101° W. at the time of the low level strong winds (southerly jet). The area could be extrapolated back to the Pacific Coast where it had been associated with a Pacific storm, the occluded front of which hit the northern California coast on the morning of September 2. No well organized 3-hour pressure change area could be discerned in connection with this storm. The 24-hour katallobaric center moved about 12° in longitude per 24 hours with rises of 2 to 5 mb. per 24 hours both to the rear and ahead of it. It should be pointed out that the speed of the pressure fall area was about twice that of the trough aloft at 4 km., and therefore no association with this feature could be made.

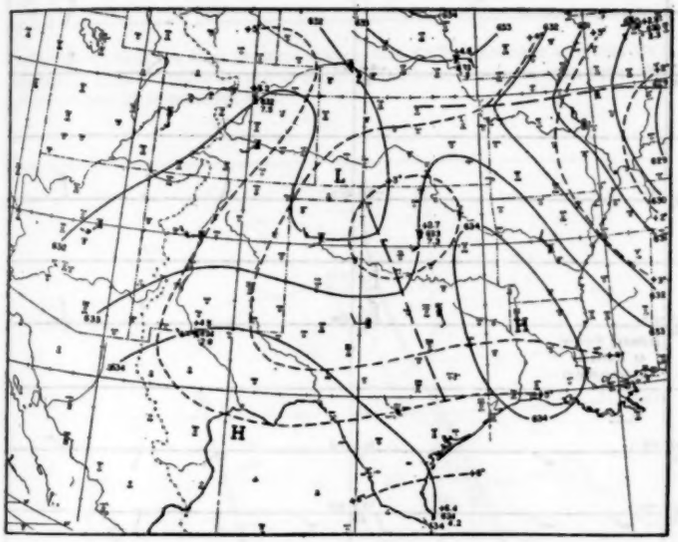

FIGURE 19.—4-km. chart showing isobars (solid lines labeled in mb.) and isotherms (dashed lines, ° C.) for 0100 EST, and winds for 0500 EST, September 3, 1940.

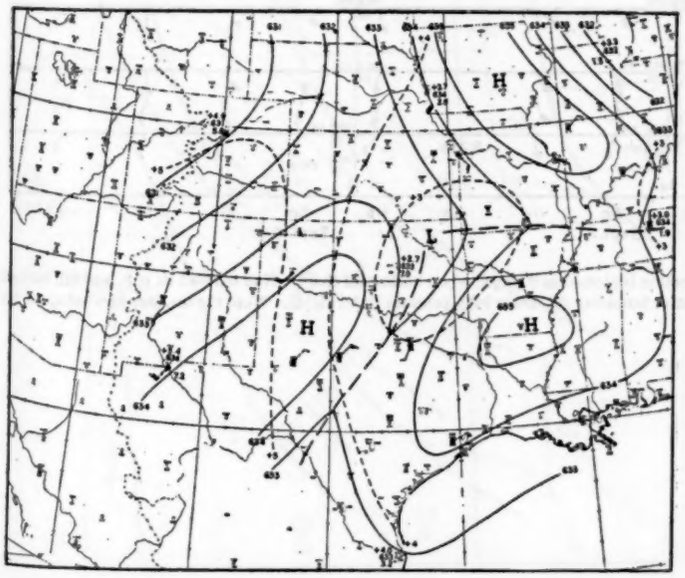

FIGURE 20.—4-km. chart showing isobars and isotherms for 0100 EST and winds for 0500 EST, September 4, 1940. Trough to east of Rockies which weakened at 3 km. as shown in figures 17 and 18 is still well marked at 4 km. just before the rain began.

To test whether this pressure fall area was in fact associated with the increase in southerly winds at low levels, the Amarillo upper winds (not shown) were examined. These showed a marked increase (from a previous velocity of 20 m. p. h. to a velocity of 40 m. p. h. from the south) at the 2300 EST observation of the 3d at 900 meters above the surface. This was 6 hours before the high wind of 50 m. p. h. at 600 meters above the surface at Oklahoma City. It might be well to point out that only a small part of this increase could be attributed to a normal diurnal variation in wind speed.

The time cross-section (fig. 21) for Oklahoma City shows an increase in wind speed of about 5 m. p. h. through the lowest 2,500 meters between the 1700 EST observation and the 2300 EST observation on the 3d. (The cold air was well established in the Oklahoma City area by the time of the latter wind observation.) Subsequently (at 0500 EST of the 4th) the wind increased at the 1,000-meter level about 25 m. p. h. above its value for 2300 EST, September 3. This corresponds well with the 20-m. p. h. increase recorded at Amarillo, Tex., 6 hours earlier. It may be concluded that most of the increase in wind speed at Oklahoma City was not due to the intrusion of low level cold air or the rainstorm itself, but resulted from an increased pressure gradient brought about by a fall in pressure to the west and a rise to the east of the rainfall area.

Examination of the rainfall recorder record for Wichita, Kans. (not shown), shows that the heavy rain burst occurred in a 2-hour period ending at 0700 EST of the 4th, corresponding closely to the time that the low level southerly jet was passing Oklahoma City. (Oklahoma City and Wichita are almost in a north-south line.)

The progression of rainfall from northwest (an unusual feature of this storm) may be explained by the fact that the combination of a northwest-southeast orientation of the cold air mass edge (nearly stationary then in regard to its southwest component of motion) and an eastward progression of the belt of strong southerly winds would produce an apparent movement of the rain burst from the northwest toward southeast.

Figures 24 and 25 illustrate schematically a solution to conditions that prevailed in the rather thin cold air mass at 750 meters over northeastern Oklahoma on the morning of September 4. Figure 24 shows observed conditions at 2300 EST and 0100 EST (times of upper wind and radiosonde observations). Figure 25 shows the observed winds and probable conditions of temperature at 0500 EST.

At 750 meters above sea level over Oklahoma City cold air is found at 0100 EST and warm air at 0500 EST (as judged from the time cross-section fig. 21). The wind at Oklahoma City was southeast about 25 m. p. h. at 2300 EST, but by 0500 EST it had increased to 45 m. p. h. from the south. At Kansas City no increase in wind

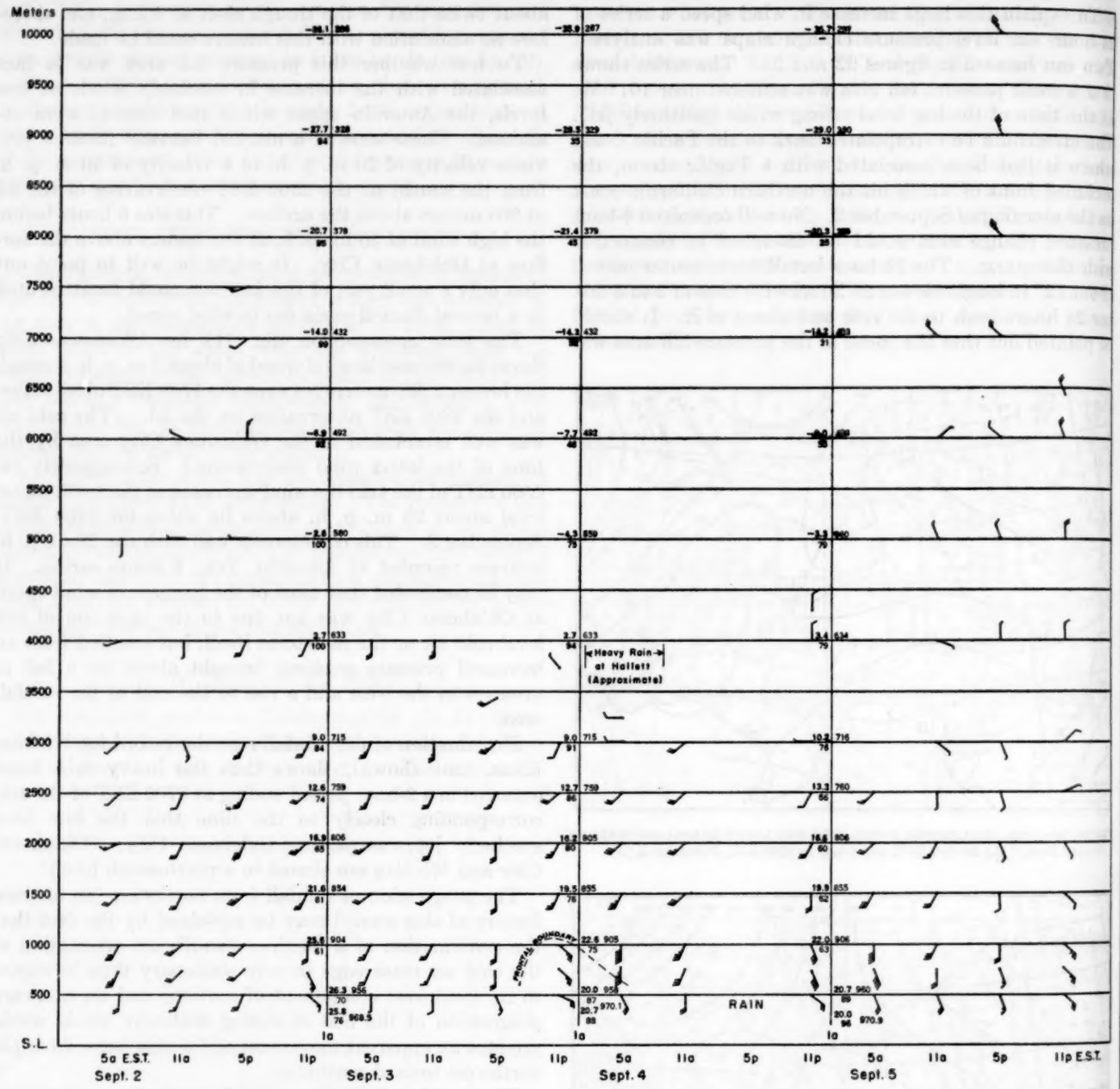

FIGURE 21.—Time cross section at Oklahoma City, Okla., September 2-5, 1940. Wind direction is plotted as if projected on horizontal chart. Half barb=5 m. p. h. and full barb=10 m. p. h. wind force. The plotted upper air data show temperature (° C., upper left), relative humidity (%, lower left), pressure (mb., right). Note the increase in wind speed and decrease in temperature in the lower levels.

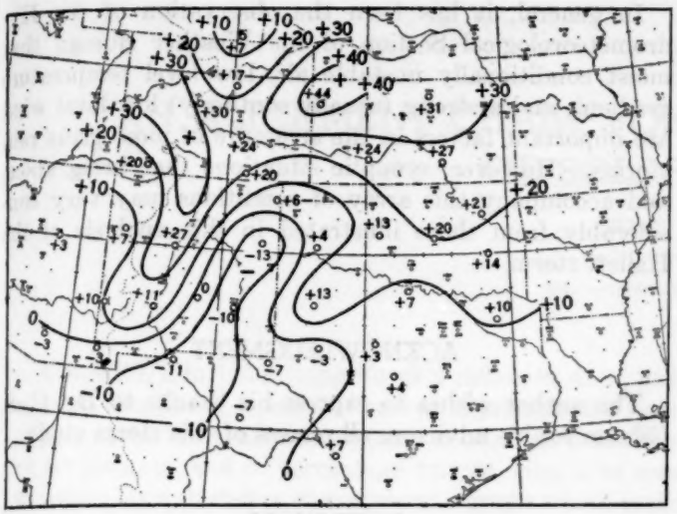

FIGURE 22.—24-hour sea level pressure change, 0130 EST, September 3 to 0130 EST, September 4, 1940. Isallobars are in tenths of millibars. Compare with figure 23 to see movement of pressure-fall area.

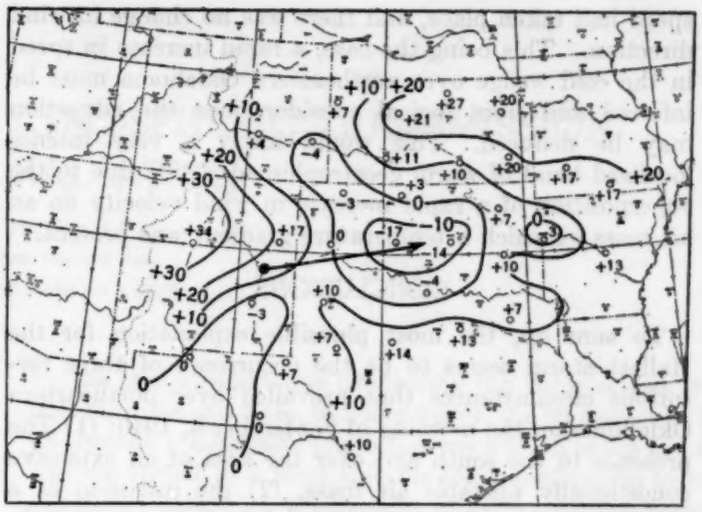

FIGURE 23.—24-hour sea level pressure change, 1330 EST, September 3 to 1330 EST, September 4, 1940. Isallobars are in tenths of millibars. Arrow indicates 12-hour movement of the pressure fall area.

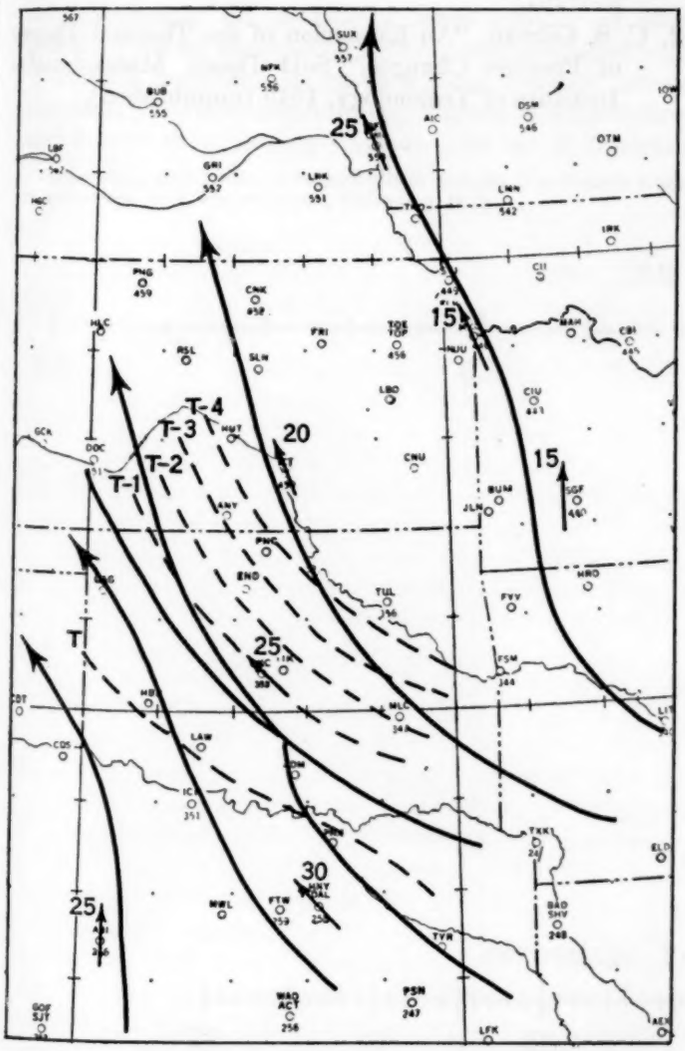

FIGURE 24.—Schematic 750-meter chart showing conditions over northeastern Oklahoma on the morning of September 4 just before the rain began. Analysis based on 2300 EST September 3 upper winds and 0100 EST September 4, 1940, radiosonde. Compare with figure 25.

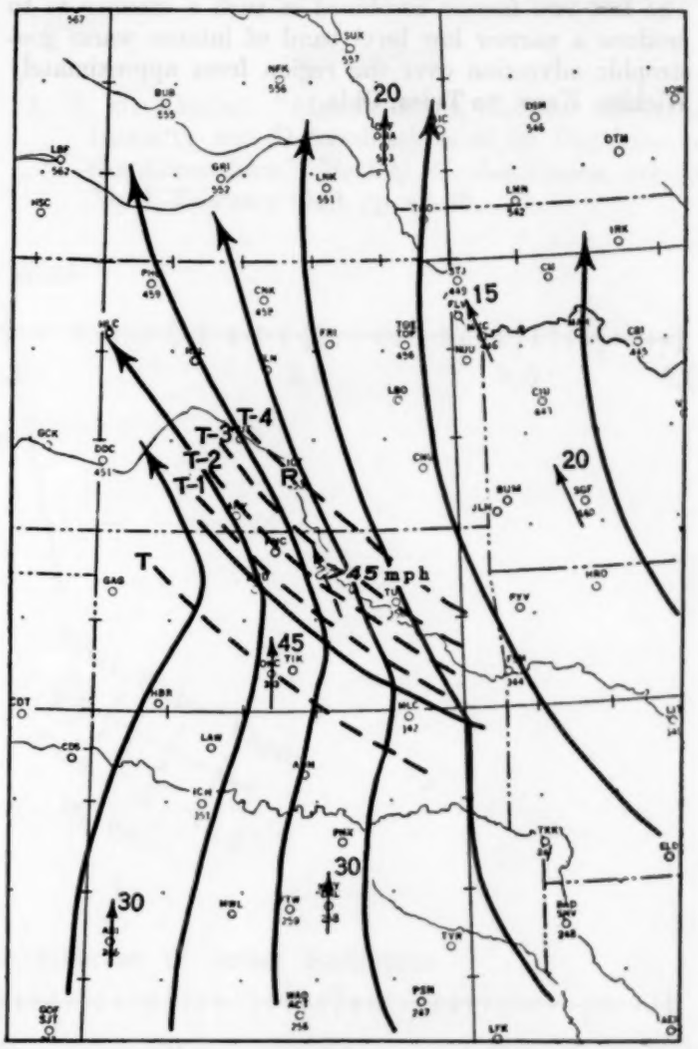

FIGURE 25.—Schematic 750-meter chart during heavy rain. Analysis based on probable temperature conditions and observed upper winds for 0500 EST September 4, 1940.

242385—53——2

speed had taken place, and there was no change in wind direction. This being the case, a rapid increase in speed in the cold wedge over northeastern Oklahoma must be inferred and from logical considerations the advection may be deduced. This would imply a very intense localized band of warm geostrophic advection due to the superposition of a rapid increase in wind velocity on an air mass in which a temperature gradient was present.

CONCLUSIONS

To sum up, the most plausible explanation for the Hallett storm seems to be the occurrence of three fortuitous circumstances that prevailed over northeastern Oklahoma on the morning of September 4, 1940: (1) The presence to the south and over the area of an extensive conditionally unstable air mass, (2) the intrusion of a thin layer of cold air at the surface from an easterly direction, and (3) a nearly concurrent increase of low level southerly winds as the result of an eastward moving katallobaric area associated with an old Pacific Low. The last two factors combined in such a manner as to produce a narrow low level band of intense warm geostrophic advection over the region from approximately Wichita, Kans., to Tulsa, Okla.

In general, it has been the observation of the Hydrometeorological Section of the Weather Bureau that moist conditionally unstable air, low level temperature gradient, and a strong (usually southerly) low level wind are important factors in the structure of most great rain storms. However, synoptic situations that bring about and accompany this array of conditions may vary considerably from those illustrated in this analysis of the Hallett storm.

ACKNOWLEDGMENT

The author wishes to express his thanks to Dr. C. S. Gilman for his advice in all phases of this storm study.

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AN ALIGNMENT CHART FOR ATMOSPHERIC TRANSMISSION OF SOLAR RADIATION

FRANK GIFFORD, JR.*
Lowell Observatory, Flagstaff, Ariz.

[Manuscript received September 2, 1952]

Kimball [1], in 1930, using Fowle's radiation data, gave a graph containing a series of curves of precipitable water vapor, w, in the total atmospheric column as a function of air mass, m, and of percentage transmission, t, of solar radiation by a dust-free atmosphere, a graph which is still in use. Absorption by both water vapor and dry air, as well as molecular scattering, are considered in the data on which Kimball's work is based. Although it suffices for one, or several transmission determinations, his graph is not convenient for making a large number of them quickly. As an alternative, figure 1 was developed when it became necessary to make a large number, several thousand, of transmission determinations in a short time, and it proved to be very efficient. Its use is illustrated by the thin straight line connecting the three scales; for unit air mass and 5 cm. of water vapor, the transmission is 68 percent. Kimball's graph (curves 9 to 15 of his fig. 1) was converted to a form suitable for transforming to an alignment chart by graphically altering the horizontal coordinate in such a way as to make the water vapor curves straight lines. For this reason there will be slight differences between his graph and figure 1, but these will never amount to more than one percent of the transmission values.

*Manuscript prepared while on temporary leave from the U. S. Weather Bureau. Present address: U. S. Weather Bureau, Washington, D. C.

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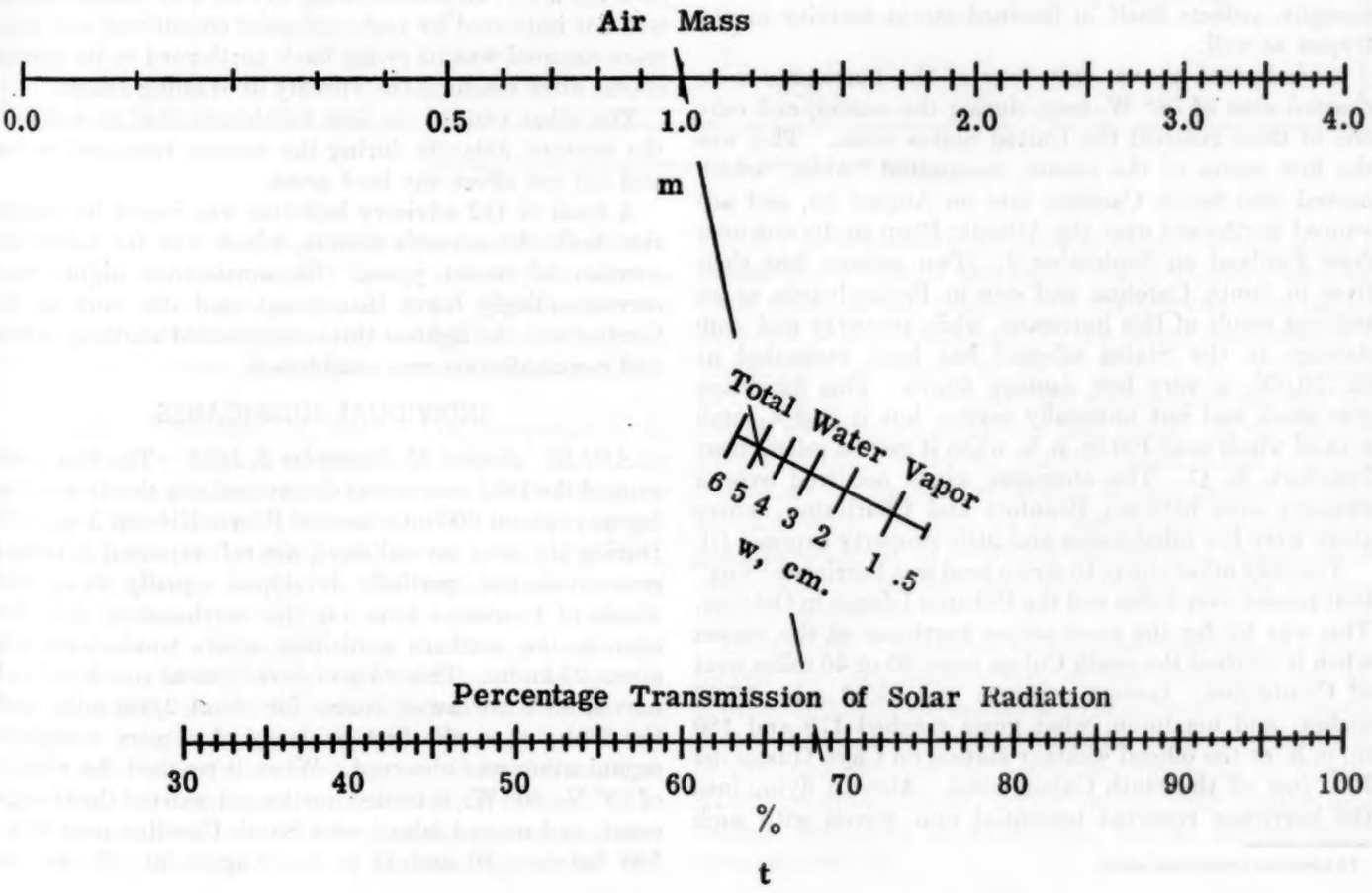

FIGURE 1.—Nomogram for atmospheric transmission of solar radiation by dust-free air. Based on Kimball's curves [1].

HURRICANES OF 1952

GRADY NORTON
Weather Bureau Office, Miami, Fla.
[Manuscript received January 12, 1953]

GENERAL SUMMARY

Hurricane activity in the Atlantic was below normal in 1952 for the first time since 1946. Six storms were charted and all of them attained hurricane force at some period in their histories. (See fig. 1.) Two of them would probably not have been discovered had it not been for the long arm of airplane reconnaissance because they remained over the Atlantic far to the east of the Lesser Antilles during their short life spans. The low hurricane activity was in keeping with past experience for summers with widespread drought over the eastern half of the United States. A study [1] of drought summers during the past half century indicates that on the average only about half as many hurricanes occur in the season following them as after normal or wet summers. This suggests that the general pressure distribution which causes widespread drought, reflects itself in lessened storm activity in the tropics as well.

As indicated above, only four of the hurricanes were charted west of 58° W. long. during the season, and only one of them reached the United States coast. This was the first storm of the season, designated "Able," which moved into South Carolina late on August 30, and advanced northward over the Atlantic Plain to die out over New England on September 2. Two persons lost their lives in South Carolina and one in Pennsylvania as an indirect result of this hurricane, while property and crop damage in the States affected has been estimated at $2,750,000, a very low damage figure. This hurricane was small and not unusually severe, but it had a small area of winds near 100 m. p. h. when it moved inland near Beaufort, S. C. The strongest winds occurred over a swampy area between Beaufort and Charleston, where there were few inhabitants and little property exposed [1].

The only other storm to strike land was hurricane "Fox" that passed over Cuba and the Bahama Islands in October. This was by far the most severe hurricane of the season when it reached the south Cuban coast 30 or 40 miles west of Cienfuegos. Lowest pressure was 933.6 mb. (27.57 inches) and maximum wind gusts reached 170 and 180 m. p. h. at the official weather station on Cayo Guano del Este just off the south Cuban coast. Aircraft flying into the hurricane reported torrential rain driven with such force by the wind that the paint was stripped from the nose and all leading surfaces of the plane, and turbulence was the most severe the crew had ever experienced. Fortunately no very large communities were hit in Cuba, but the rural areas affected were severely damaged. The excellent warning service is given credit for the fact that no lives were lost. Commander Millás of the National Observatory at Havana gave the Miami Hurricane Central the best possible cooperation, and the special surface and upper air observations furnished from Cuban stations made the excellent warnings possible. This was another of those very small but very severe hurricanes from the western Caribbean for which October is famous.

Hurricane Fox lost much of its violence in crossing Cuba, but retained winds of 100 m. p. h. or better as it moved on an erratic course through the Bahama Islands. (See fig. 2.) The erratic swing to east and east-southeast was not indicated by meteorological conditions, and even more unusual was its swing back northward to its normal course after reaching the vicinity of Watling Island.

The other two, of the four hurricanes that moved over the western Atlantic during the season, remained at sea and did not affect any land areas.

A total of 112 advisory bulletins was issued in connection with the season's storms, which was far below the number of recent years. Reconnaissance flights were correspondingly fewer than usual, and the work at the Central was the lightest since coordinated warning service and reconnaissance was established.

INDIVIDUAL HURRICANES

ABLE. August 25–September 2, 1952.—The first hurricane of the 1952 season was discovered as a slowly developing wave about 600 miles east of Puerto Rico on August 25. During the next several days, aircraft reported it to be a crescent-shaped, partially developed, squally wave, with winds of hurricane force on the northeastern side, but open in the southern semicircle, where winds were only about 25 knots. This state of development continued as it moved on a northwest course for about 2,000 miles until the 29th, when the first evidence of a more completed organization was observed. When it reached the vicinity of 30° N., 80° W., it turned northward, skirted the Georgia coast, and moved inland over South Carolina near Beaufort between 10 and 11 p. m., August 30. It was the

[1] An informal unpublished study.

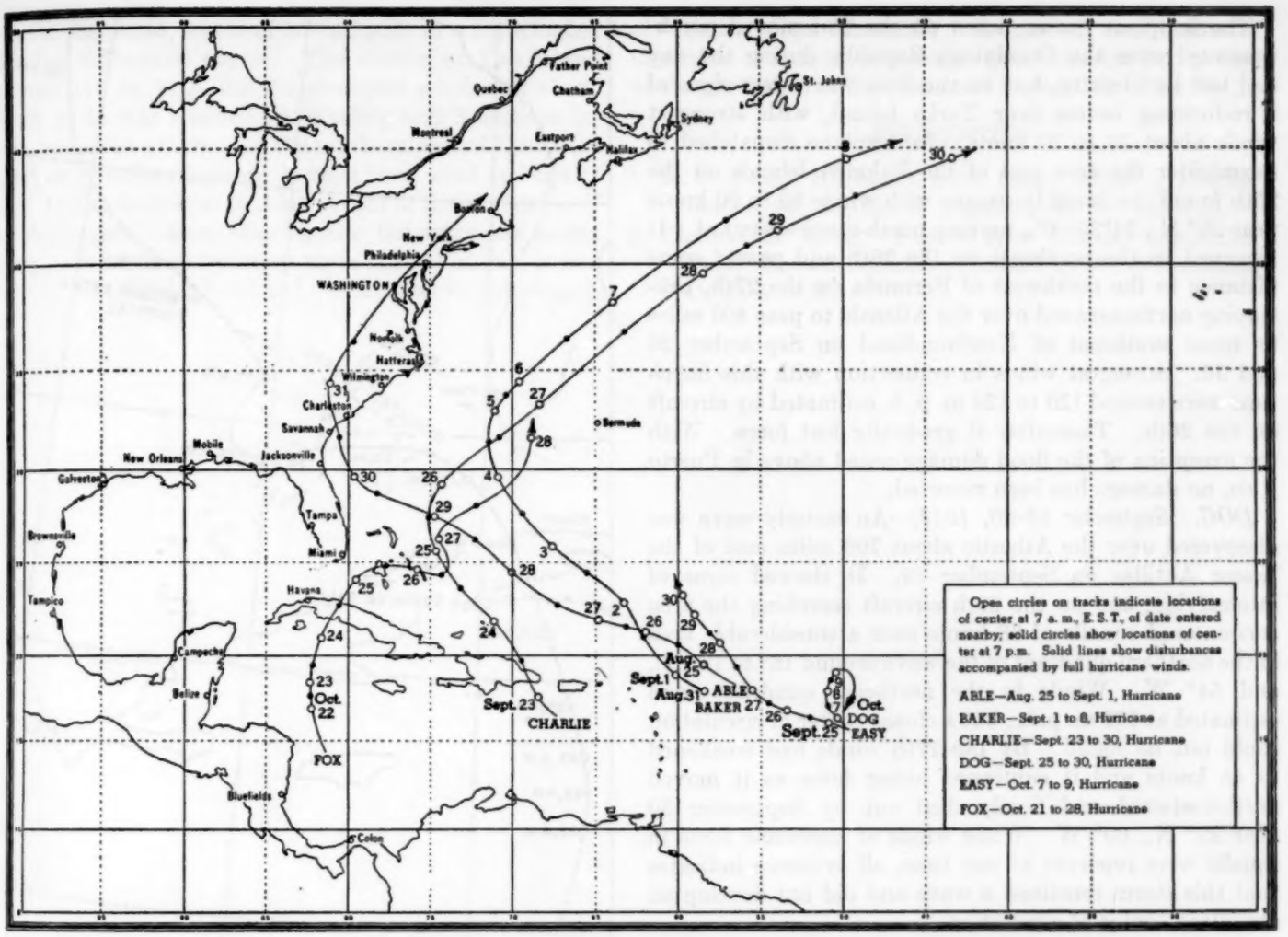

FIGURE 1.—Tracks of hurricanes observed during the 1952 season.

indirect cause of two deaths in South Carolina, and one death in Pennsylvania, and property and crop damage in the Atlantic States was estimated at $2,750,000. For an analysis of this hurricane and further detailed information, see *Monthly Weather Review* for August 1952, pages 138–143 [1].

BAKER. September 1–8, 1952.—The Norwegian S. S. *Fridtjof Nansen* located at 18°45′ N., 58°45′ W. in the early morning of September 1 sent a special report as follows: "Wind easterly force 7 to 8 in squalls, sea 5 increasing, barometer 30.02 inches at 0300Z, 29.90 at 0400Z. Fear tropical storm and have altered course to 70° 8 knots at 0400Z, after which barometer steady at 29.90 inches." This report was the first indication of the development of the second hurricane of the season. Reconnaissance aircraft dispatched to search later on the 1st, found that the storm had developed winds of hurricane force on its northern and eastern sides and was increasing and moving on a northwesterly course.

The course continued northwestward during the next several days, until it reached the vicinity of 32° N., 71° W., on September 5. Here it began curving along a course which carried the center about midway between Cape Hatteras and Bermuda on the 6th and then northeastward over the Atlantic. In the period September 2–6 winds were estimated at 100–115 m. p. h. with gusts to 140 m. p. h. This hurricane remained at sea and did not give strong winds at any land point. It moved out over the Atlantic several hundred miles south of Newfoundland on September 7 and 8, and passed beyond aircraft range. A total of 25 advisories were broadcast enabling shipping to avoid the hurricane or maneuver to miss the strongest part, and no reports of marine damage have been received.

CHARLIE. September 23–29, 1952.—An easterly wave moved into the eastern end of the Carribean Sea on September 22 and showed some signs of developing a center just south of Mona Passage on September 23. Just prior to this, the wave caused heavy flooding rains on Puerto Rico September 22–23, which caused four deaths and damage estimated at $1,000,000, but no strong winds were reported [2].

The incipient center noted on the 23d moved northwestward over the Dominican Republic during the day and lost its identity, but on the 24th there were signs of a re-forming center near Turks Island, with strongest winds about 20 to 30 knots. An airplane dispatched to reconnoiter the area east of the Bahama Islands on the 25th found the small hurricane with winds 80 to 90 knots near 26° N., 74°30′ W., moving north-northwestward. It recurved to the northeast on the 26th and passed some distance to the northwest of Bermuda on the 27th, continuing northeastward over the Atlantic to pass 400 miles or more southeast of Newfoundland on September 29 and 30. Strongest winds in connection with this hurricane were around 120 to 125 m. p. h. estimated by aircraft on the 26th. Thereafter it gradually lost force. With the exception of the flood damage noted above in Puerto Rico, no damage has been reported.

DOG. September 25–30, 1952.—An easterly wave was discovered over the Atlantic about 700 miles east of the Lesser Antilles on September 25. It showed signs of intensifying, and on the 26th aircraft searching the area encountered squalls of 68 knots over a considerable area in the northern quadrant of the wave around 16° to 18° N., and 54° W. Winds in the northeast quadrant were estimated at 100 m. p. h., but a closed center of circulation could not be found. By the 27th winds had weakened to 45 knots and it continued losing force as it moved northwestward and finally died out by September 30 near 23° N., 60° W. While winds of hurricane force in squalls were reported at one time, all evidence indicates that this storm remained a wave and did not develop an organized center of circulation.

EASY. October 7–9, 1952.—This storm flared briefly to hurricane intensity and then as rapidly dissipated over the Atlantic about 700 miles east of Antigua, B. W. I. It was located by reconnaissance aircraft on October 7 with maximum winds of only about 40 knots, but on the 8th, the plane encountered winds of 95 knots near the center. The flight on October 9 found that winds had dropped to 42 knots and thereafter it died out. The hurricane moved very little during its existence, but remained in the vicinity of 17°–18° N., and 50°–51° W. Without the extension of our view provided by B–29 reconnaissance planes, this hurricane would doubtless have gone undetected.

FOX. October 22–28, 1952.—The last hurricane of the 1952 season was the most severe. It developed from a perturbation on the intertropical convergence zone that was first noted in the western Caribbean Sea north of the Canal Zone on October 21. It increased to hurricane force on the 22d when it was about 150 miles east of Swan

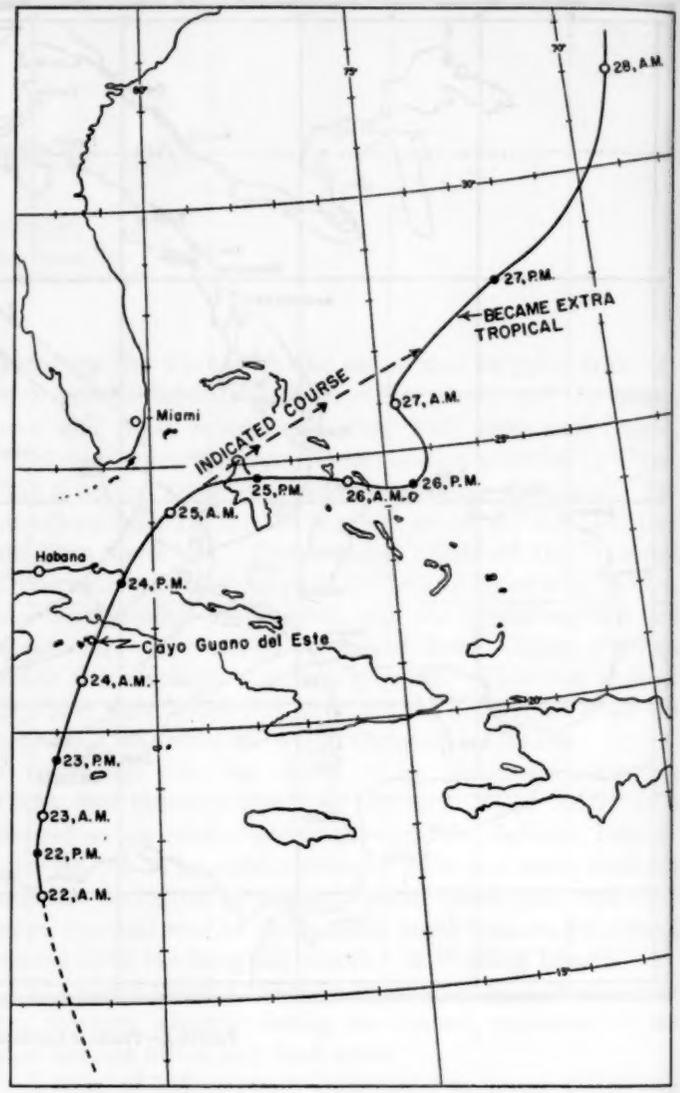

FIGURE 2.—Track of hurricane "FOX." October 1952. Note unusual path between 25th and 27th.

Island, and thereafter moved northward with increasing intensity and crossed Cuba on the 24th as the very severe small hurricane described earlier in this article. The passage over Cuba was through the rural sugar cane plantation section, and it was reported that 36 of Cuba's 161 sugar mills were in the storm area and suffered damage in addition to the heavy damage to the cane crops. The largest community struck was the inland town of Aguada de Pasajeros (25,000 population) where about 600 homes were destroyed, and a thousand or more damaged. No dollar estimate of the damage has been received, but no lives were lost. Strongest winds reported 180 m. p. h. and lowest pressure 933.6 mb. (27.57 inches) at Cayo Guano del Este.

In the Bahamas, winds of 100 m. p. h. or a little higher attended the erratic course. The station on Cat Island reported 110 m. p. h. for the strongest wind, and about 100 m. p. h. was reached on Watling and Eleuthera Islands, and a few others. In the southern part of Eleuthera Island crops suffered severe damage from wind and heavy rain. It was estimated that 30 percent of the tomato crop was destroyed. After clearing the Bahamas the storm swung back north to resume a more normal course, it was joined by an old polar front and became a wave disturbance of extra-tropical character. It moved northeastward thereafter as a disturbance of no great violence and passed to the northwest of Bermuda on October 28. (See fig. 2.)

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THE WEATHER AND CIRCULATION OF JANUARY 1953[1]

KENNETH E. SMITH
Extended Forecast Section, U. S. Weather Bureau, Washington D. C

THE WEATHER

The month of January 1953 was filled with extremes of weather over much of the Northern Hemisphere. Most notable of all were the disastrous floods beginning on the 31st which affected Great Britain and the lowland countries of Europe. These were reported to be the worst floods in that part of the world in 500 years. At last reckoning, more than 1,400 lives were lost and property damage was measured in billions of dollars. Contributing causes to this disaster will be discussed in another section.

In contrast to the floods in Europe, serious drought conditions developed in parts of the Hawaiian Islands. By the end of the month, the ground had become parched and grass in most areas was dead. It was reported that the leeward areas of Hawaii and Maui were most affected, and that several days of heavy rain were badly needed to prevent crop failure. Elsewhere in the Pacific, several shipwrecks and airplane crashes occurred in unusually strong winds. On the 9th, mountainous seas and gale winds capsized a ship 100 miles west of Pusan, Korea, with 233 lives lost. During the same week, gales caused the splitting in two of the Swedish ship *Avanti* northwest of Okinawa.

Over the United States, one of the warmest Januarys ever recorded was experienced (Chart I), with only the Florida peninsula showing slight negative temperature departures from normal. Unseasonably warm weather prevailed over most of the country during every week of the month. Average January temperatures at Helena and Missoula, Mont., and Salt Lake City, Utah, were the highest on record. In the Plateau region maximum temperatures rose to record or near-record levels on numerous days throughout the month and this was reported to be one of the warmest Januarys ever known. Cold polar outbreaks were generally weak and short-lived. The most severe one of the month occurred on the 15th and 16th in the Great Plains and Mississippi Valley. This was preceded by blizzard conditions in Iowa, South Dakota, and parts of neighboring States during which from 2 to 7 inches of drifting snow blocked many roads and forced some rural schools to close. Some of the lowest temperatures of the month followed this storm with −41° F. at Orr, Minn., and −36° at Danbury, Wis. Freezes which occurred in most of the Southeast on the 4th and 5th, and again on the 12th and 13th, did some damage to vegetables.

In general, precipitation averaged less than normal in the Southwest, Great Plains, and Mississippi Valley regions (Chart III). Elsewhere it was above normal, with over twice the normal amount in the Pacific Northwest, southern Florida, and sections of New England. The worst storm of the month for the East developed over Texas on the 8th and moved into the Southeast on the 9th, bringing heavy rains and thunderstorms to that area. Twenty-four-hour precipitation amounts at Birmingham and Key West exceeded 4 inches. This storm was responsible for several tornadoes that hit central Florida and left a mile wide swath of damage through the resort city of Sarasota. As the storm moved northeastward, heavy snow and ice in New York and New England disrupted electric power, transportation, and communication systems in large areas. The storm took 19 lives in New England and was reported as the biggest wintry storm to hit Boston in seven years. Another weather extreme occurred at Salt Lake City on the 14th as a cyclone developed on a cold front that had moved in from the Pacific. 14.7 inches of snow, a record 24-hour amount, fell, damaging roofs, trees, and power lines.

Due to repeated heavy rains, some minor flooding occurred in western Oregon and Washington during the second week, and considerable flooding north of Eureka with heavy flood damage in western Oregon was reported during the 3d week of the month.[2] A shallow but vicious norther which preceded a Texas cold spell blew deep into the Texas midlands on the 23d, dumping up to 10 inches of snow at Aiken, closing roads, stranding motorists, and snapping power and telephone lines, while drenching rains and winds of almost hurricane force battered the central and east Texas area.

GENERAL CIRCULATION CHARACTERISTICS

The mean 700-mb. circulation for January, 1953 (fig. 1) was quite similar to that for December 1952 [1] in many respects. Heights continued much greater than normal throughout the North Atlantic, with departures as high as +450 feet approximately 800 miles west of Great Britain. Over Europe, heights remained below normal, with one anomaly center of −330 feet over

[1] See Charts I to XV following page 30 for analyzed climatological data for the month.

[2] See adjoining article by Hughes and Roe for additional details.

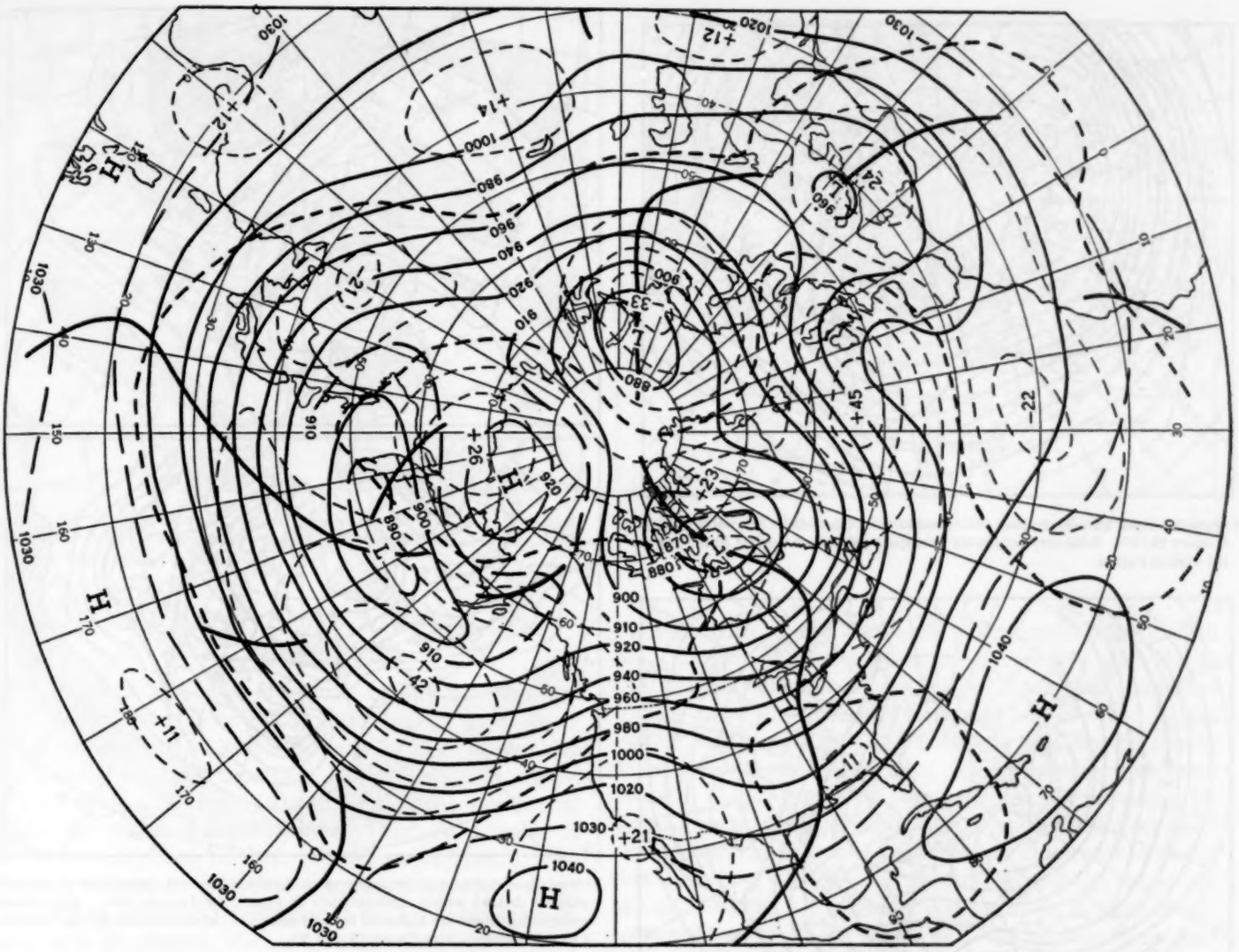

FIGURE 1.—Mean 700-mb. height contours (solid) and departures from normal (dashed) for December 30, 1952-January 28, 1953. Note greater than normal flow of warm maritime air into the United States.

extreme northwest Russia and another of −240 feet near Italy. These centers, coupled with the large positive anomaly west of Great Britain, created a much stronger northerly gradient than normal from the west coast of Europe eastward to Russia, a factor of considerable importance for the European flood.

Over North America, the major long wave trough was located in a position almost identical to that it had in December, extending from northern Labrador south-southwestward through the Great Lakes region, the Mississippi Valley, and the western Gulf of Mexico. Once again, heights averaged above normal in central and northern sections of this trough, and it was only over the southeastern States that heights fell to slightly below normal. The greatest negative anomaly observed anywhere in the United States (−100 feet) occurred over Alabama and Georgia in connection with this trough. Throughout the western United States anticyclonic conditions persisted, but this month the ridge was developed more strongly than normal with positive height anomalies reaching +200 feet, whereas in December, it was slightly weaker than normal. The strength of this ridge, coupled with stronger than normal southwesterlies blowing in from the Pacific, contributed to the abnormal warmth in the West (Chart I). The Pacific was again dominated by broad cyclonic flow at middle latitudes as heights continued below normal throughout most of the central and north Pacific and above normal at southerly latitudes. Greatest negative values (−400 feet) occurred near 43° N., 150° W. while greatest positive anomalies (+100 feet) were centered around 17° N., 175° W. Between these anomaly centers stronger than normal westerlies, displaced farther south than normal, contributed to the weakness of rain-bearing trade winds in the Hawaiian area and the resulting drought. Associated with the southerly displacement of the westerlies was the

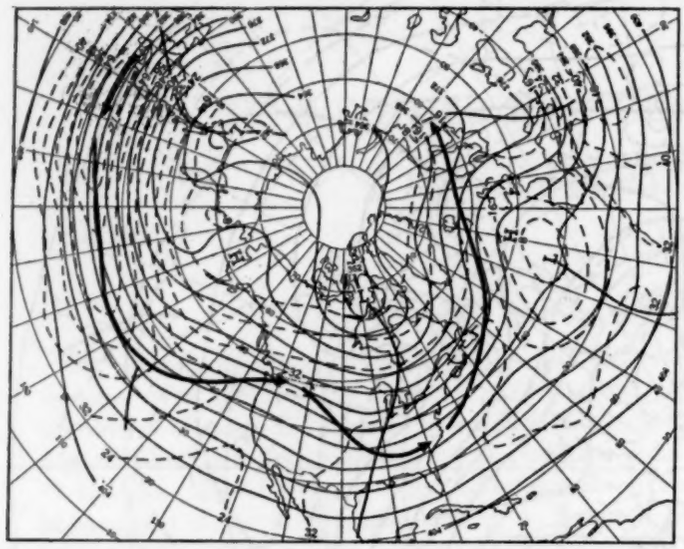

FIGURE 2.—Mean 200-mb. contours (solid) and isotachs (dashed) for December 30, 1952-January 28,1953. Solid arrows indicate principal "jet" which reached 80 m. p. s in the western Pacific.

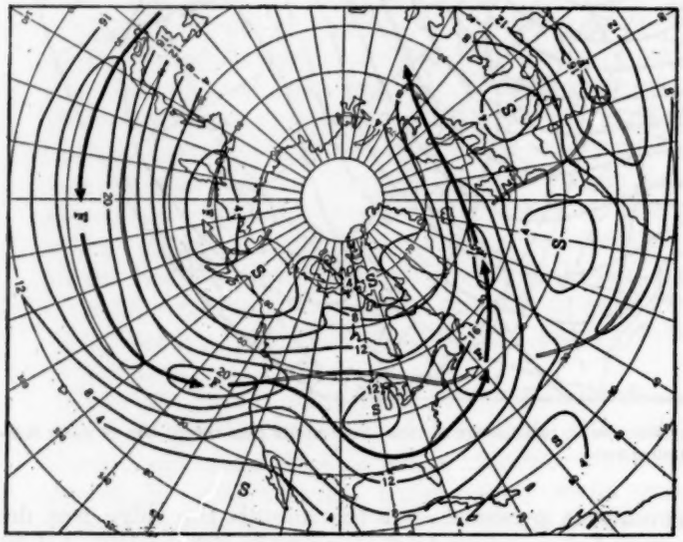

FIGURE 3.—Mean 700-mb. isotachs for December 30, 1952-January 28, 1953. Solid arrows indicate principal jet, while open arrows indicate secondary jets. Note split jet in United States, secondary jet in western Europe, and easterly jet in Bering Sea.

development of an upper level High over western Alaska, the northern Bering Sea and extreme northeastern Siberia. Positive height anomalies as much as 260 feet occurred in connection with this High.

Comparing figures 2 and 3, it is seen that there is very close parallelism between the main jet streams at 700 mb. and 200 mb., with the latter stream, in general, being located slightly to the north of the former. Of particular interest is the strong jet stream at middle latitudes in the Pacific, with winds for the month averaging as high as 25 meters per second at 700 mb. and 80 meters per second at 200 mb. An easterly "jet" around the upper level High in the vicinity of the Bering Sea (fig. 2) is

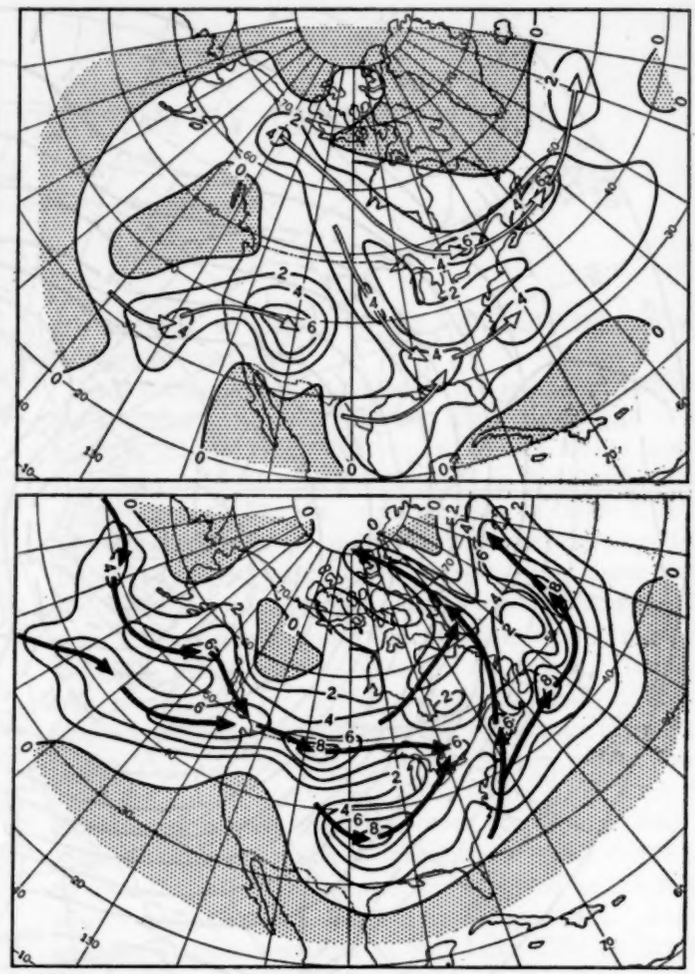

FIGURE 4.—Geographical frequency of anticyclonic passages (above) and cyclonic passages (below) within approximately 5° squares for January 1953. Well defined anticyclonic tracks are indicated by solid arrows and cyclonic tracks by open arrows. (All data obtained from Charts IX and X).

also noteworthy. As the 700-mb. jet stream crossed the United States, it split into two distinct branches, one traversing the northern border and one passing through the Gulf States. The cyclone tracks (fig. 4B) across North America followed the split jet fairly closely. Storms entered North America in the vicinity of Washington and British Columbia, with one favored path being located along the northern border of the United States and the other from the southern Plains area northeastward through the eastern Great Lakes and New England. These storm paths were quite consistent with locations of heaviest precipitation (Chart III). Anticyclone tracks (fig. 4A) were not so closely related to the jet. After moving out of Canada, one path curved southeastward just north of the Great Lakes while the other moved southeastward into southeastern United States. A third path from the eastern Pacific into the Great Basin is especially noteworthy.

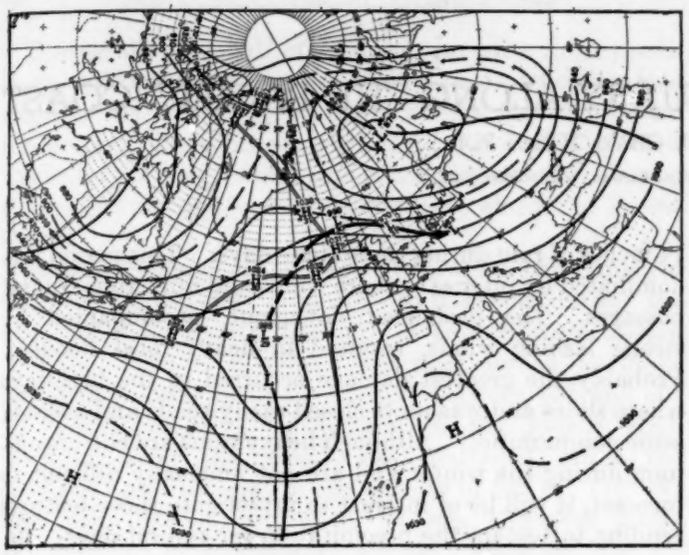

FIGURE 5.—Five-day mean 700-mb. contours for January 28–February 1, 1953. Solid and open arrows are paths of surface Low and Highs, with intensity in millibars, above, and day of month below.

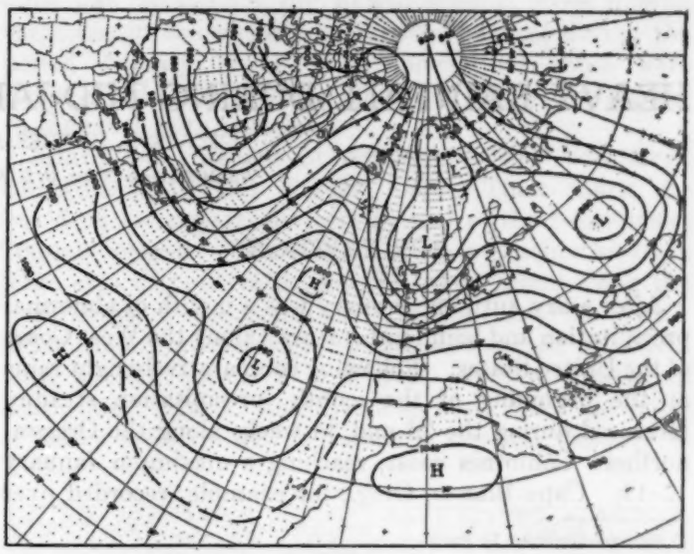

FIGURE 6.—700-mb. contours for 0300 GMT, January 21, 1953. Unusually strong gradient between Iceland and Great Britain is evident.

SOME FACTORS ASSOCIATED WITH THE GREAT EUROPEAN FLOOD

Astronomical and meteorological factors combined to produce the worst flood in modern history in western Europe on January 31 and February 1. The inundation was caused by strong northerly to northwesterly winds, reported to have reached 114 m. p. h. at times, reinforcing a high tide which was exceptionally high as a result of the full moon. Two distinct critical stages, timed with high tide, occurred. The first, varying from late evening of the 31st in Scotland to morning of the 1st in the Netherlands, was, in general, the most disastrous, since winds were strongest. The second stage occurred during the afternoon and evening of the 1st. It was reported that 12-foot waves occurred with the first and 9-foot waves with the second high tide in the Low Countries.

Figure 5 shows the 5-day mean 700-mb. height for the period January 28–February 1, 1953, together with the paths of the surface Low and Highs which produced this catastrophe. Figure 6 shows the daily 700-mb. map for 0300 GMT, January 31, approximately 12 hours before the first floods occurred. Noteworthy on the latter chart is the exceedingly strong gradient between Iceland and France, and the intense trough between western Russia and Turkey. The Low responsible for the flood began in the vicinity of the Azores on the 29th, exact position being doubtful due to lack of reports. By the morning of the 30th (EST), it had moved northeastward, apparently steered by the long wave ridge, and was located between Iceland and Scotland, with central pressure 990 mb. During the next 24 hours it recurved sharply to the southeast, again consistent with the flow indicated by the mean contours, and deepened to 970 mb. It was during this period that the northerly and northwesterly winds increased tremendously. Both the daily and mean 700-mb. charts suggest a strong confluence of warm air moving northeastward from the Atlantic and cold air moving southeastward from Greenland, an important factor in this deepening [2]. By the morning of the 1st, the storm had filled to 983 mb. and had continued its motion southeastward into northern Germany. During the storm passage, a cold polar High, which had moved southeastward from Greenland, combined with a maritime High, which had moved northeastward from the Atlantic, in the vicinity of Scotland. The juxtaposition of these Highs with the low center contributed to the strong northerly gradient in the rear of the storm.

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HEAVY RAINFALL DURING MID-JANUARY ALONG THE PACIFIC COAST

GROVER D. HUGHES AND CHARLOTTE L. ROE

WBAN Analysis Center, U. S. Weather Bureau, Washington, D. C.

INTRODUCTION

After a dry autumn, January was a month of abnormal precipitation and high temperature [1] along the West Coast of the United States. Following comparatively light rains at the beginning of the month, precipitation steadily increased during the 2d and 3d weeks along the Oregon-northern California coast, reaching a maximum January 17–19. Cape Blanco, Oreg., for example, recorded over 14 inches of rain during these three days. This period was dominated by intense onshore winds and numerous frontal passages. The prolonged downpour, accompanied by strong lashing winds, resulted in heavy local flooding. Probably the greatest damage occurred to the highways where slides and washouts closed many roads and isolated some communities. Although heavy rains are not uncommon during the winter and are not unusually difficult to forecast, it will be of interest to investigate those features tending to sustain the precipitation for several days.

[1] See preceding article by Smith.

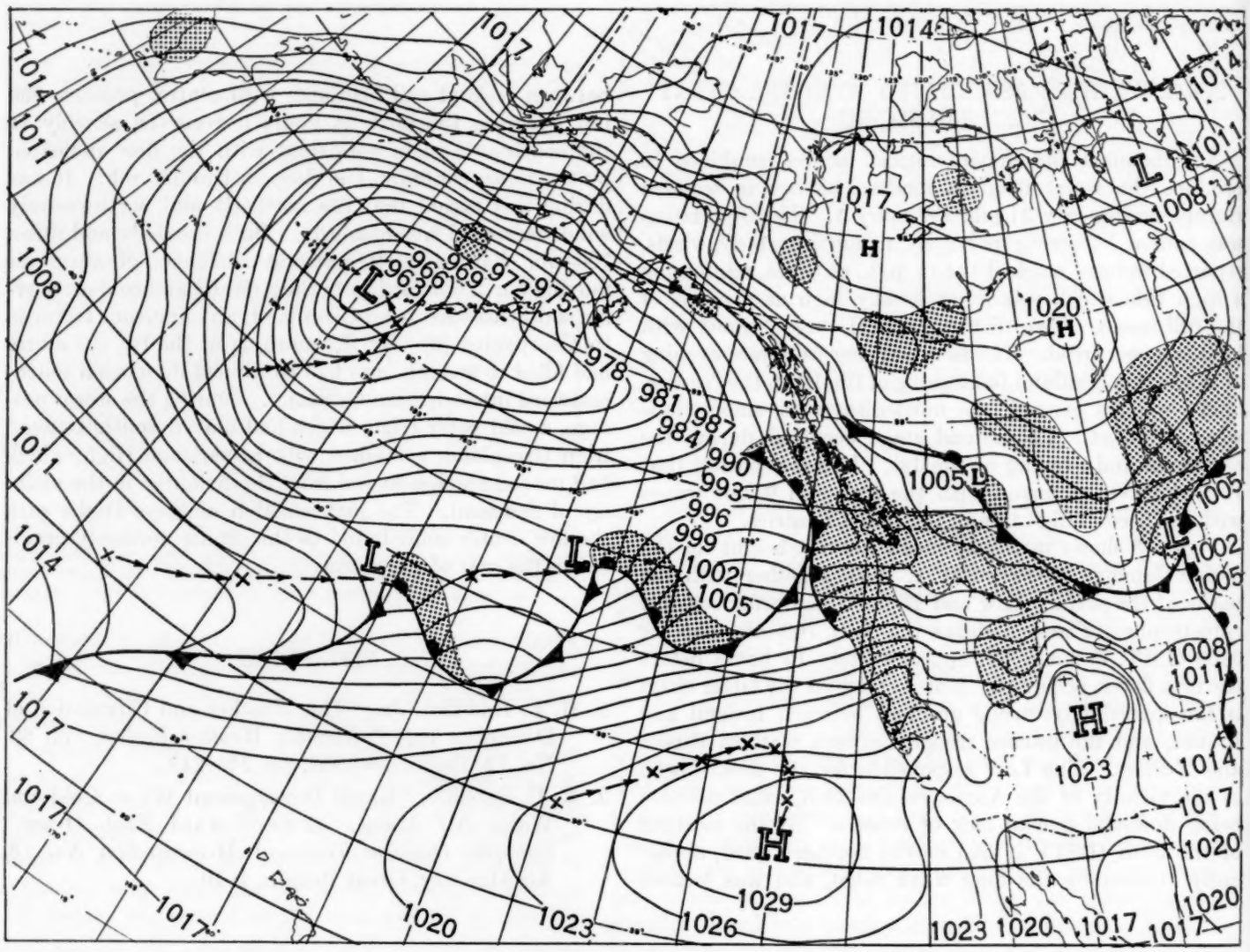

FIGURE 1.—Surface weather chart for 0030 GMT, January 18, 1953, illustrating the widespread cyclonic flow over the Northern Pacific. Shaded areas indicate active precipitation. Past positions are shown for 12-hour intervals.

METEOROLOGICAL CONDITIONS

During the first half of January, pressure ridge conditions aloft existed along the West Coast, deflecting into Canada the migratory surface systems moving toward the coast. The southern portion of the frontal systems weakened as they moved under the ridge aloft. During this period rainfall was relatively light along the Pacific Coast.

Near mid-January, a surface High, which had remained relatively stationary in northwest Canada during the first half of the month, began to move southward toward Alberta. Frontal systems were then forced to move inland at a lower latitude—namely between 40° and 50° N. Simultaneously, the portion of the Pacific High extending over the West Coast flattened, while the Aleutian Low deepened in the vicinity of 50° N., 170° W. The entire Pacific north of 35° N. was, therefore, under the influence of a uniform cyclonic circulation (fig. 1). At this time heavy rains began along the Pacific Coast. This precipitation was produced by a combination of several factors, each contributing to the rainfall. In this section, we will investigate the various elements in detail.

In Washington, Oregon, and northern California, topography plays a most important role in the rainfall distribution. From the rugged Pacific coastline, elevations of the Coast Range in southern Oregon and northern California rise abruptly to 5,000- to 7,000-foot peaks. In California, the Sacramento Valley is located between this range and the much higher Sierras. As the Coast Range flattens rapidly to the north, the Cascades become the dominant range running through Oregon and Washington with average elevations of 6,000 to 9,000 feet and peaks extending to 12,000 feet. Mount Rainier just to the west of the range reaches 14,408 feet. Along the Oregon-California border the Coast Range, Cascades, and Sierras merge into one mountainous region. Mount Shasta, elevation 14,162 feet, is the predominate feature here. All these ranges, rising rather precipitously from the Pacific and generally oriented in a north-south direction, constitute an effective barrier against low level winds and moisture.

The rate of orographic precipitation depends largely upon the strength of the flow normal to the mountain barrier [1]. The 5-day mean sea level pressures for the period January 14–18 (fig. 2) indicate west-southwest flow from the Pacific onto the Oregon and northern California coasts. Figure 3 shows that sea level pressures were about 10 mb. higher than normal off the California coast and 5 to 10 mb. lower than normal west of Washington with a strong gradient increase in the area between 40° and 45° N. The intense gradient was not confined exclusively to the surface. The mean 700-mb. chart (fig. 4) and its departure from normal (fig. 5) also indicate excessive west-southwest flow. The jet stream at the 500-mb. (fig. 6) and 300-mb. levels entered the coast in the vicinity of Portland, Oreg., during the period January 17–19. This shows that winds were strong at all levels with the maximum winds zone sloping to the north with altitude.

Martin and Hawkins [3] have drawn "wet" and "dry" composite charts for Eureka, Calif. Their charts are based on the departures from normal of the 5-day mean 700-mb. heights. The "dry" chart is dominated by a large area of positive departures from normal along the west coast of the continent. In contrast, the "wet" chart has an intense negative area in the Gulf of Alaska with a slight positive area from southern California southward. Martin and Hawkins state that the cause of heavy precipitation at Eureka is a strong westerly to

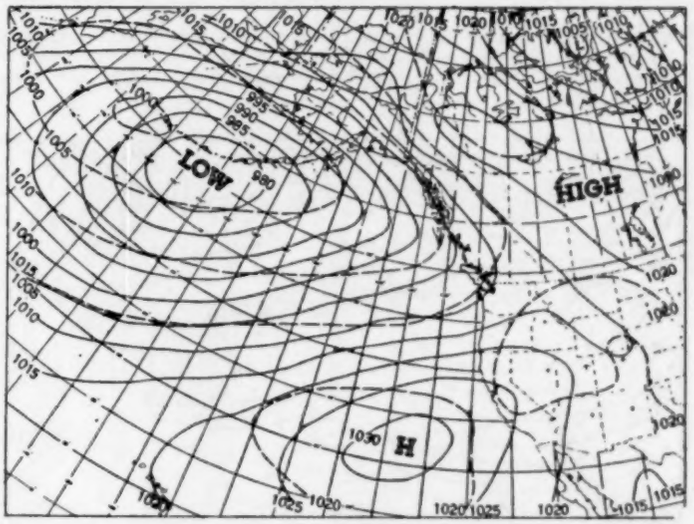

FIGURE 2.—5-day mean sea level isobars (solid lines) January 14–18, 1953, compared with the normal January sea level isobars [2] (dashed lines). Isobars are labeled in millibars.

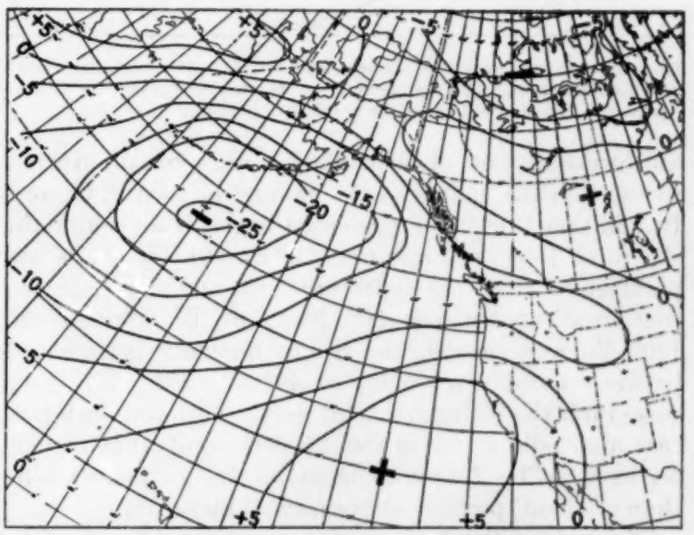

FIGURE 3.—Departure of 5-day mean sea level pressures (mb.) from monthly normal, January 14–18, 1953. Note the indications of a tight gradient between San Francisco and Seattle.

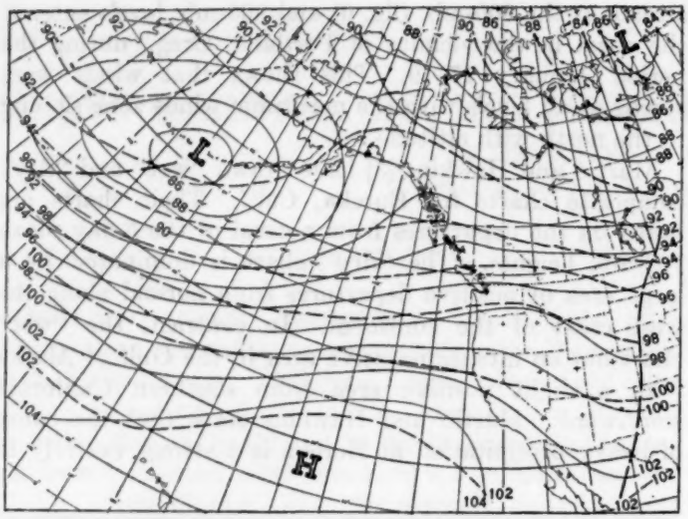

FIGURE 4.—5-day mean 700-mb. contours (solid lines) January 14–18, 1953, compared to the normal January contours (dashed lines) [2]. Heights are labeled in hundreds of geopotential feet. Note that the gradient between San Francisco and Portland, Oreg., is twice the normal.

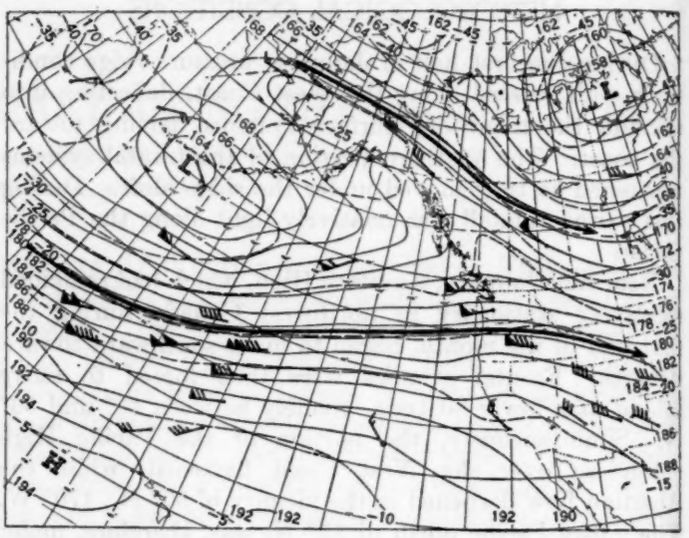

FIGURE 6.—500-mb. chart for 0300 GMT, January 18, 1953. Contours (solid lines) are labeled in hundreds of geopotential feet, isotherms (dashed lines) in ° C. Note that the maximum winds zone (heavy lines) enters the coast near Portland, Oreg.

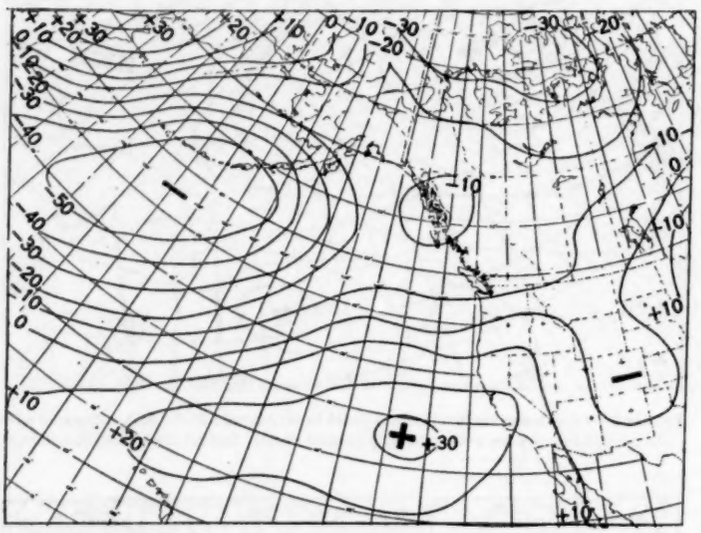

FIGURE 5.—Departure from normal of 5-day mean 700-mb. heights (tens of geopotential feet), January 14–18, 1953. The magnitude of the negative area near the Aleutians agrees well with Martin and Hawkins "wet" type chart [3].

southwesterly flow of moist Pacific air, a condition which was met in the January case, as may be seen in figure 5. In addition they have presented a graph for estimating the total 5-day precipitation for Eureka by use of two parameters, first, the departure from normal of the contour gradient between 50° N., 130° W. and 30° N., 110° W. and second, the height anomaly intermediate between these two points at 40° N., 120° W. From this graph the estimated total 5-day precipitation for the case under discussion is about one-third of what actually occurred. The difference must be due to factors other than gradient, perhaps above normal moisture.

Throughout the 3-day period under consideration, and during the preceding week, frontal systems were entering the coast approximately one per day. These systems were forming as waves on the polar front about 1,000 miles northwest of the Hawaiian Islands (fig. 1). Originating from a position more southerly than usual and imbedded in the large cyclonic flow aloft in existence over the Pacific, these waves were accelerated east-northeastward and occluded as they approached the Washington-Oregon coast. In general, the fronts were extremely difficult to follow especially after they moved inland. Examination of the hourly rainfall totals indicates that precipitation was fairly uniform during these three days with only slight maxima concurrent with the frontal passages. One might conclude, therefore, that the fronts were of minor importance in producing the rain.

Since the strength of the flow against the mountains has been established, and the effect of the frontal systems minimized, we shall investigate the origin of the air mass with particular emphasis on moisture and stability. Cold polar air masses moving off Alaska or Asia over the warmer waters of the Pacific Ocean are modified by warming and increasing moisture in the lower layers. The amount of modification varies directly with the length of trajectory over the water; a shorter trajectory, from Alaska or Canada to the West Coast and then inland, favors a more convectively unstable air mass [1]. Tropical air masses moving northward are cooled from below, thus becoming stabilized in the lower layers and actually losing a small amount of moisture by condensation.

A study of the upper air soundings at Medford, Oreg. (not reproduced), shows that the temperatures at 500 mb. were too cold to be of tropical origin, and therefore must have been from a polar source. These same soundings show high moisture content below 500 mb.—evidence that the polar air had a long maritime trajectory. Examination of figures 1 and 3 indicates that such air would have originated over Alaska or more likely Siberia, then moved

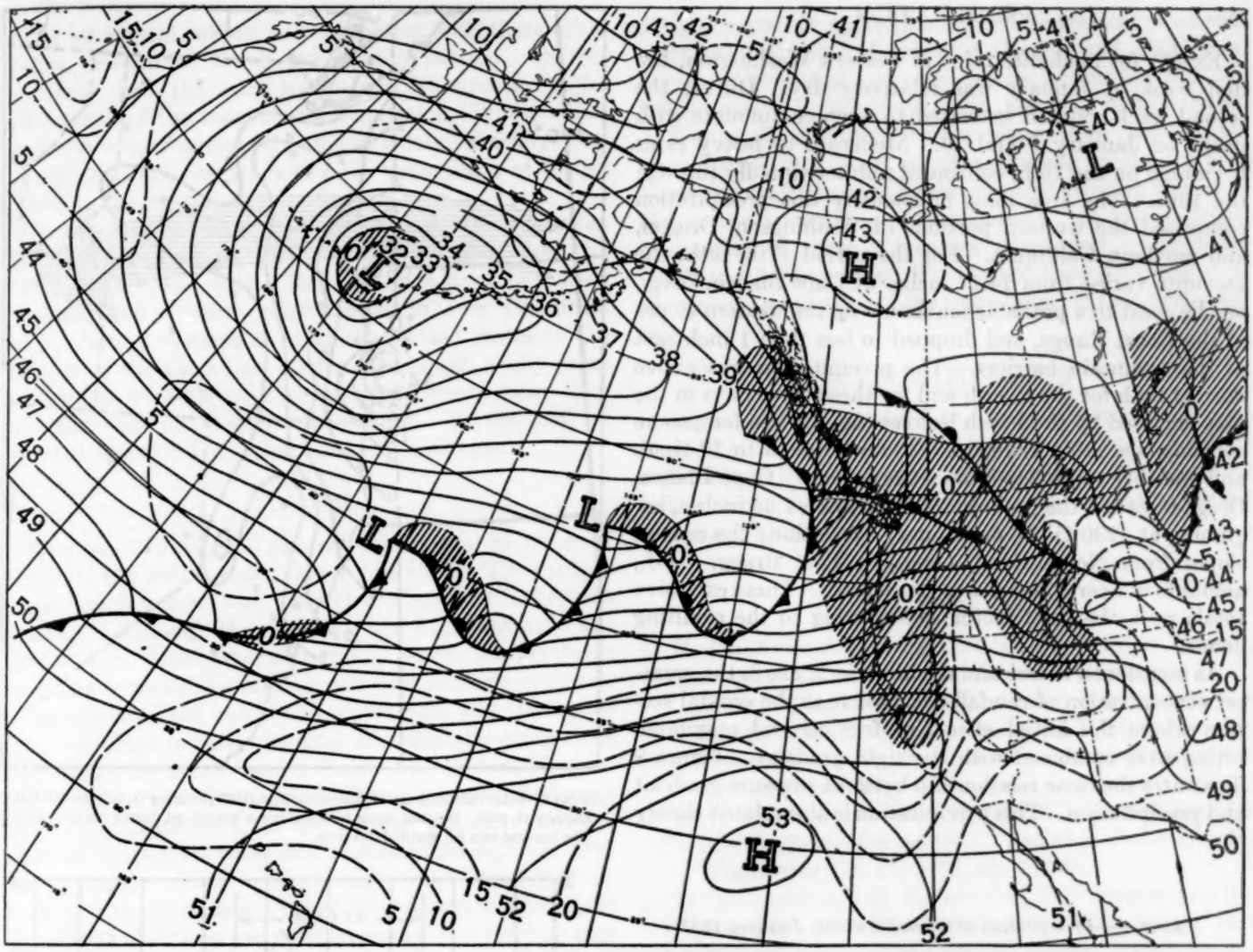

FIGURE 7.—850-mb. chart, 0300 GMT, January 19, 1953. Contours (solid lines) are labeled in hundreds of geopotential feet. Dew point depressions, $T-T_d$, (dashed lines) are in ° C. with areas of zero depression shaded.

southward to the region northwest of the Hawaiian Islands, and finally, modified considerably in its lower layers, advanced toward the West Coast from the southwest. Air with this history would be quite moist and conditionally unstable, i. e., identified as mPk becoming mTk.

The surface layer was unusually moist as indicated by 60° F. dew point temperatures reported by ships along the coast. Lines of equal dew point depression ($T-T_d$), a measurement of saturation, at the 850-mb. level (fig. 7) show the presence of a moist tongue along the frontal zone. It is common knowledge that West Coast rainfall is directly related to the gradient and moisture. Putting this to practical use, forecasters in the area employ a quantitative precipitation forecasting graph,[1] which relates expected rainfall amounts to predicted winds and surface dew points. Several objective methods for forecasting precipitation at West Coast cities have been developed using the parameters of gradient and moisture. Others rely primarily on pressure gradient (for example see Thompson [4]).

Surveying the above conditions we find a combination of strong west-southwest winds, coastal mountain ranges, and a moist unstable airmass. The coalition of these factors is repeatedly found along the West Coast during frontal passages. However, it is unique for this combination to persist over a particular area for a prolonged period. Usually the area of tight gradient and associated orographic rainfall will migrate from Washington southward to California with the period of appreciable amounts lasting less than 24 hours at any one locality. In this specific case the strong flow of moist air normal to the northern California-Oregon coastal mountains persisted for three days with only slight fluctuations due to the numerous frontal passages.

[1] T. E. Jermin, W. O. Peterson, and others, "Rainfall Computation Charts, Seattle Forecast District", Seattle, Nov, 1948. (Processed manuscript.)

PRECIPITATION

Except for moderate rains in western Washington, the first week of January was relatively dry. During the second week, rainfall increased to average amounts with peaks on January 9 and 10. Moderate to heavy rains beginning on the 16th, continued uninterruptedly through the 19th. The area most affected by this precipitation comprised the western portions of Washington, Oregon, and northern California. For the period 17th-19th, the amounts varied from 14.17 inches at Cape Blanco, Oreg., on the coast to a probable maximum on the western slopes of the Coast Range, and dropped to less than 1 inch east of the mountain barriers. The precipitation was above normal both for the month and for these three days in the area enclosed by the 1 inch isohyet (fig. 8). In fact, some stations (see table 1) reported 3-day totals 6 to 10 times and monthly totals 2 to 3 times the normal. Cape Blanco, Oreg., recorded the greatest 24-hour total, 7.66 inches, beginning at 1230 GMT on January 17. Along the coastal slopes from North Bend, Oreg., to Fort Bragg, Calif., amounts of over 3 inches were measured. These excessive totals were the chief factor contributing to the resulting floods.

As mentioned before and as shown in figure 8, the greatest concentration of rainfall occurred near the coastal section where the initial effects of friction and maximum lifting were combined with the tight gradient. Figure 9 illustrates the close relationship between pressure gradient and precipitation. This precipitation is also related closely

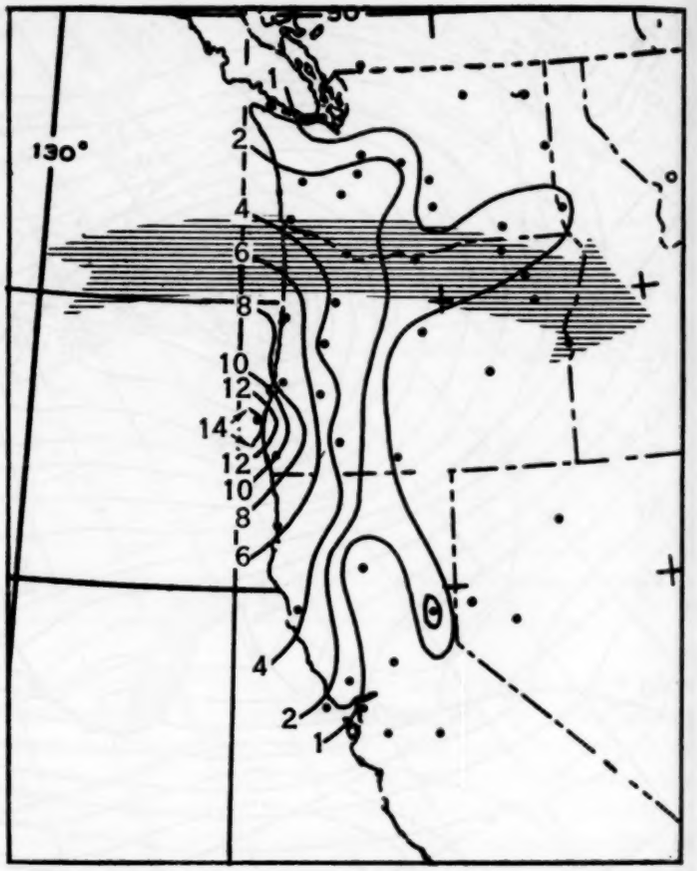

FIGURE 8.—3-day rainfall isohyets (inches) for 1230 GMT, January 16, 1953, to 1230 GMT, January 19, 1953. Hatched arrow indicates mean 300-mb. jet during the same period. The heaviest rain fell south of this zone.

TABLE 1.—*Precipitation at selected stations, January 1953*

Station	Total month	Departure from normal	3-day total 17-18-19 (0800-0800 GMT)	3-day normal [6] 17-18-19	3-day total / Total month ×100 percent
					Percent
Spokane, Wash.	4.56	+2.84	0.55	0.16	12
Seattle, Wash. (FOB)	10.93	+6.44	1.16	.42	11
Tacoma, Wash.	9.57	+4.60	1.08	.48	11
Ellensburg, Wash.	3.01	+1.81	.69	.12	23
Olympia, Wash.	19.84	+13.15	2.14	.60	11
Yakima, Wash.	2.67	+1.71	.49	.09	18
Lewiston, Idaho	2.88	+1.83	.73	.10	27
Kelso, Wash.	12.24	+7.14	1.53	.45	12½
Walla Walla, Wash.	4.52	+2.84	1.15	.15	26
Pendleton, Oreg.	2.88	+1.40	1.13	.15	39
Portland, Oreg. (CHB)	14.67	+9.24	2.23	.51	15
Meacham, Oreg.	9.29	+4.99	3.50	.42	38
Salem, Oreg.	15.40	+9.68	2.80	.54	18
Baker, Oreg.	1.40	+.39	.43	.11	31
Eugene, Oreg.	11.13	+5.72	2.51	.51	23
Burns, Oreg.	1.98	+.51	.75	.12	38
Roseburg, Oreg.	10.16	M	3.06	.45	30
Sexton Summit, Oreg.	10.14	+6.12	3.49	.39	34
Medford, Oreg.	5.49	+2.98	2.32	.24	41
Mt. Shasta, Calif.	8.38	+3.84	1.51	.42	18
Eureka, Calif.	12.63	+6.43	5.92	.60	47
Red Bluff, Calif.	3.56	−.17	.76	.36	21
Blue Canyon, Calif.	19.10	+9.93	4.17	.90	22
Sacramento, Calif. (POB)	3.51	+.65	.58	.27	17
San Francisco, Calif. (FOB)	3.26	−.77	.72	.39	22
Oakland, Calif.	2.04	−1.26	.49	.30	24

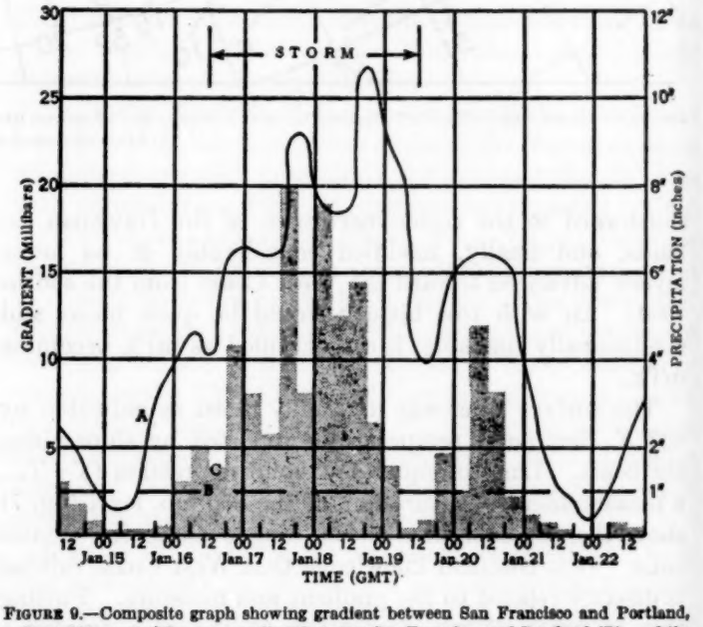

FIGURE 9.—Composite graph showing gradient between San Francisco and Portland, Oreg. (A), normal January gradient between San Francisco and Portland (B), and the combined totals of 6-hourly precipitation (C) at the following coastal stations: Fort Bragg, and Eureka, Calif., Brookings, Cape Blanco, North Bend, and Newport, Oreg. Note the relationship between gradient and precipitation.

to the jet stream, which, in conjunction with these other factors determined the heavy rainfall pattern. In this particular case, the mean upper-level jet stream was located north of the maximum precipitation (fig. 8). This bears out what Starrett [5] found in a detailed study, that precipitation activity tends to be in the vicinity of the jet stream in the westerlies.

On the 20th the deep Low near the Aleutians started filling, thus decreasing the strong zonal flow over the Pacific and West Coast. The Gulf of Alaska Low then deepened and a warm ridge moved in over California forcing frontal systems to enter the United States in the vicinity of the Canadian border. Although heavy rains occurred on the 20th and 21st along the Oregon coast, they generally were north of the flood areas. By the 22d, all rain had ceased in California and most of Oregon.

FLOODS

Because of moderate rainfall during the 2d week of January, the runoff index factor was high. Thus subsequent precipitation was converted almost entirely into flooding. Although the snow line was high and coverage lighter than usual, the abnormally warm temperatures would have melted enough snow to augment stream flow. Supersaturated soil conditions, snow melt, and the heavy rains combined to cause flooding on practically every river and stream in northwestern California, western Oregon, and southwestern Washington. These inundations began almost simultaneously on the smaller streams with the onset of the heavy rains and continued through the 21st on the larger rivers. Many high water records were broken. On the Klamath River, near Klamath, Calif., the January 18 discharge was 280,000 second-feet (preliminary provisional data) compared with the previous peak flow of 197,000 second-feet on February 2, 1952. Similarly, the Salmon River at Somesbar, Calif., attained a maximum rate of 41,000 second-feet on the 18th, almost 11,000 second-feet greater than the previous record on December 28, 1945 [7]. In Oregon, the Rogue River reached its highest level since 1927. Of the larger rivers, the Willamette was above flood stage, while the Columbia overflowed from Vancouver, Wash., to the Pacific Ocean [8].

The damage was due primarily to erosion, although rising waters routed several thousand families from their homes and destroyed much personal property. The erosion consisted mainly of earthslides and washouts, disrupting railroad and highway traffic. In California, damage to the road systems was estimated to be between 2 and 3 million dollars in Humboldt and Del Norte counties alone, inducing the Governor to declare a state of emergency there. Northwestern Pacific Railroad officials reported approximately 50 slides and washouts blocking 265 miles of track in Oregon and California. A huge slide of mud and rock swept a locomotive into the Eel River near Scotia Bluff, Calif., resulting in 3 fatalities. A few small mountain communities were isolated for several days with food supplies running perilously low. News reports and photographs revealed swirling waters as high as the second floor of many homes. In coastal areas, evacuation of these homes was hampered by gale-like winds and 5-foot waves. These conditions prevailed over a large area during one of the worst floods in that particular region.

ACKNOWLEDGMENTS

The writers are indebted to George C. Holzworth and Donald A. Richter of the WBAN Analysis Center for their assistance in the preparation of this article. We also wish to thank the forecasters at Seattle and San Francisco for their useful comments.

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THE HEAVY SNOWSTORM OF JANUARY 28–30, 1953 AT THE EASTERN END OF LAKE ONTARIO

ERNEST C. JOHNSON
U. S. Weather Bureau Office, Albany, N. Y.
and
CONRAD P. MOOK
U. S. Weather Bureau District Forecast Center, Washington National Airport, Washington, D. C.

The occasionally important influence of local geographical features on weather happenings is dramatically illustrated in the locally heavy snowfalls which occur to the lee of the Great Lakes during the autumn and winter months. On the night of January 28–29, 1953, such a snowfall occurred in and around Pulaski, N. Y., a few miles from the eastern shore of Lake Ontario (see fig. 2) with depths of new snow as much as 3 feet being reported overnight. The snowfall occurred within a very narrow east-west band 15 to 20 miles wide.

The purpose of this article is to set forth some of the synoptic features of the weather situation accompanying this storm and its counterparts which subsequently during the immediately following 24 hours produced snowfalls of 9 inches or more in two other sections of the "eastern-end" region of New York State. Wiggin [1] reports that in January 1940 a snowburst of this type buried the eastern end of Lake Ontario's countryside and shoreline under 8 feet of snow which was blown later into drifts 20 feet high. He also states that this region, which extends roughly from Syracuse northward to Watertown, N. Y., and eastward to the Adirondack Mountains, receives more snowfall than any other area of the United States east of the Rockies.

Remick [2] describes the frictional and thermal influences on cold air currents which pass over the warmer lakes but states that Lake Erie is often ice covered in late winter and does not, therefore, produce these locally heavy snows late in the winter. Lake Ontario, however, is a much deeper lake and remains open during the entire winter.

Lansing [3] in describing heavy local snows at the eastern end of Lake Ontario states that if the winds are predominantly from the southwest, given the other necessary conditions, the Adams-Watertown area may get the snow; if westerly, the Pulaski-Sandy Creek area eastward to the Adirondacks; and if northwesterly, the Fulton-Syracuse area. Thus with a series of fast moving Lows, with winds shifting from southwest to west and from west to northwest snow could continue over this area for 2 or 3 days with each different wind component "spraying" the leeward area with bursts of snow.

A storm of this type comes into existence when a low pressure center passes northeastward across the Lakes and moves into the Canadian Provinces east of Hudson Bay and north of the St. Lawrence, where deepening occurs with partial blocking to the east. Accompanying this there must be a rather vigorous polar outbreak into the Mississippi Valley. This condition produces a flow of air across the lake. Repeated micro pressure troughs circulate around the great vortex of the low pressure system bringing about the shifting winds.

The heavy snows of January 28–30, when carefully analyzed, appear to be four separate snowstorms, affecting four different but partially overlapping regions in rapid succession accurately duplicating Lansing's model. The first snowfall was associated with a fresh outbreak of polar air which moved over Lake Ontario on January 28. (See fig. 1.) In the Pulaski, N. Y., area the snow began to fall during the evening of the 28th and continued all night. Reports of local residents indicated that up to three feet of snow had fallen at nearby Fernwood during the night, while 2 feet accumulated at Pulaski. Overnight snowfall amounts on this area are shown in figure 2 which has been reconstructed from all available information including that reported in local newspapers. (Note Stage I in fig. 2.)

However, at approximately 0700 EST of the 29th the snowbelt began to reorient itself toward the east-northeast and as the weather cleared in the Pulaski area, up to nine inches of snow fell by 1500 EST in a belt which includes Adams, N. Y., illustrated as Stage II in figure 2. The change in the general flow pattern in the lower levels of the atmosphere over and to the lee of the lake are indicated in the wind data for 2,000 feet as reported at Syracuse, N. Y. At 1600 and 2200 EST of the 28th and through 0400 EST of the 29th, the pibal at Syracuse showed a westerly wind at that level ranging from 26 to 43 knots. However, sometime between the 0400 and the 1000 EST pibal observations of the 29th, the winds shifted and came in from the southwest. The 1000 EST pibal for Syracuse shows a 14-knot wind from 240° at 2,000 feet. A glance at figure 2 shows the relatively longer lake trajectory experienced by a westerly wind reaching the Pulaski area

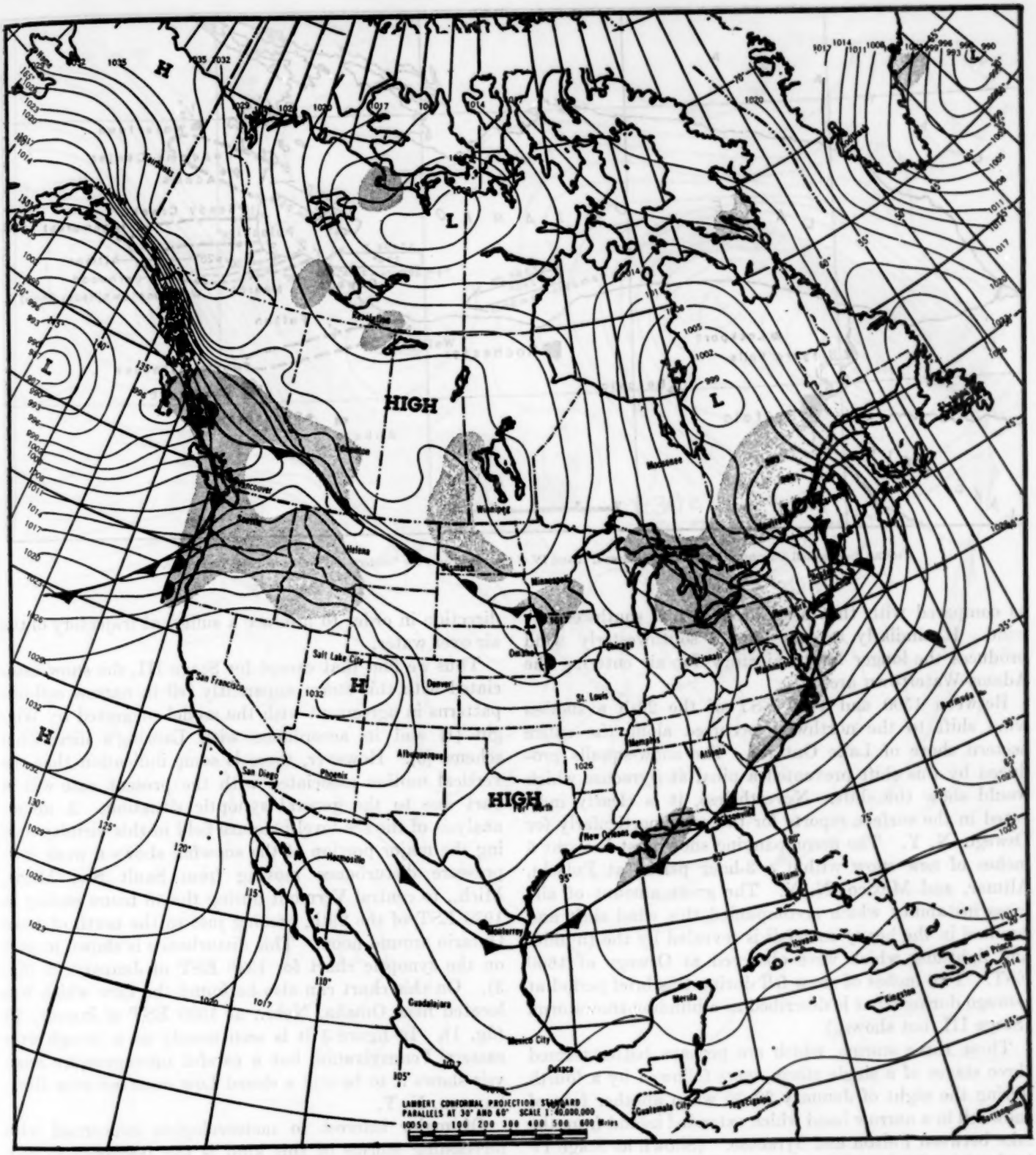

FIGURE 1.—Surface weather map for 1330 EST, January 28, 1953. Snow began to fall in the Pulaski, N. Y., area on the evening of this day and continued all night. (See Stage I in fig. 2.)

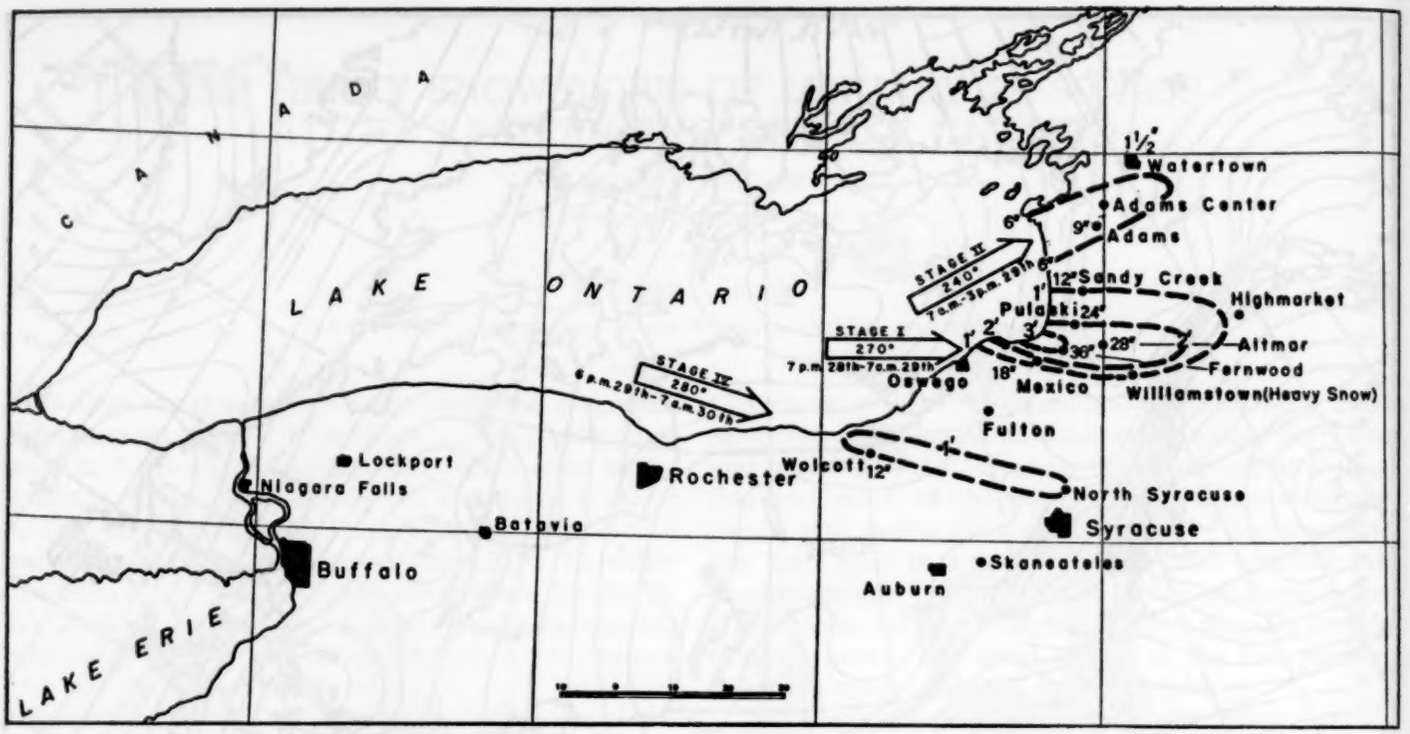

FIGURE 2.—Snowfall amounts accumulated in Stages I, II and IV of this storm over the "eastern end" region of New York State.

as compared with that associated with a southwesterly wind. It similarly reveals how a southwesterly wind produces the longer lake trajectory for air entering the Adams-Watertown area.

Between 1500 and 1600 EST of the 29th a sudden wind shift to the northwest occurred along the entire eastern shore of Lake Ontario. The snow-squalls produced by this shift prevented a pibal at Syracuse which would show the shift. Nevertheless, it is clearly indicated in the surface reports for the area, particularly for Oswego, N. Y. The accompanying snowburst brought 6 inches of new snow within a 3-hour period at Pulaski, Altmar, and Mexico, N. Y. The great amount of air-mass instability which accompanied this wind shift and resulted in the heavy snowfall is revealed by the thunder and lightning which were observed at Oswego at 1600 EST. Two inches of snow fell during this brief period at Oswego during what is described as a blinding snowstorm. (Stage III, not shown.)

These three storms, which are perhaps better termed three stages of a single storm, were followed by a fourth during the night of January 29–30 when another foot of snow fell in a narrow band which extended inland from the lake between Fulton and Syracuse. (Shown as Stage IV in fig. 2.) During this stage of the storm there was, of course, no pibal run at Syracuse, but the 0400 EST observation at Rome, N. Y., of the wind at 2,000 feet shows a 15-knot wind from 280°. An inspection of figure 1 again confirms the necessity for a sustained wind from this direction in order to produce a sufficient trajectory of the air over water.

Thus we find that except for Stage III, the snow associated with this storm apparently fell in narrow cell-like patterns in agreement with the model suggested by Wiggin [1] and in accordance with Lansing's directional scheme [3]. However, there is some indication that the vertical motion associated with the present case was in part due to the general synoptic situation. A micro-analysis of the sea-level pressure field in this vicinity during the major portion of the snowfall shows a weak low-pressure disturbance moving from Sault Ste. Marie, Mich., to central Vermont during the 18 hours ending at 1930 EST of the 29th, passing just to the north of Lake Ontario around noon. This disturbance is shown in part on the synoptic chart for 1330 EST of January 29 (fig. 3). On this chart can also be found the Low which was located near Omaha, Nebr., at 1330 EST of January 28 (fig. 1). In figure 3 it is seen merely as a trough over eastern Pennsylvania, but a careful micropressure analysis shows it to be still a closed Low centered over Binghamton, N. Y.

Of major interest to meteorologists concerned with forecasting storms of this kind is the temperature contrast between the air and water necessary to produce such snows. Remick [2] lists the contrasts associated with five outstanding local snows near Lake Erie. They range from 16° to 29° F. with the air temperatures ranging from 32° down to 18° F. Forecasters in the area are

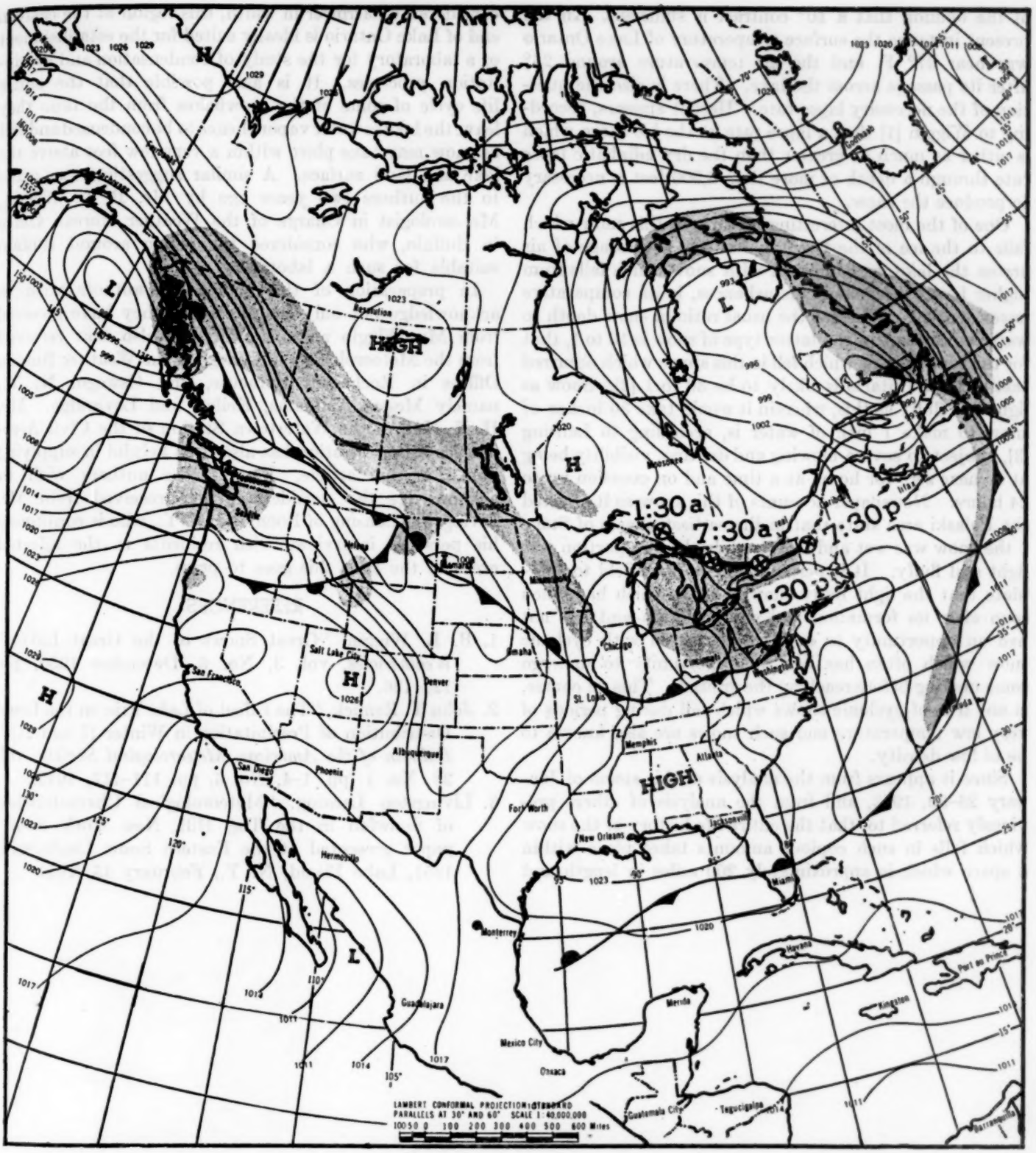

FIGURE 3.—Surface weather map for 1330 EST, January 29, 1953. (Stage II, see fig. 2.) Track shows positions of weak low pressure system which traversed the area. Another snowfall occurred during the night of January 29–30. (See Stage IV, fig. 2.)

of the opinion that a 10° contrast is sufficient. In the present instance the surface temperature of Lake Ontario was near 37° F. and the air temperature around 25° after its passage across the lake. There is also the question of the necessary lapse rate. Here it appears, according to Wiggin [1] that a lapse rate at the lee shore which is either as much or greater than the dry adiabatic lapse rate through a depth of more than 5,000 feet is necessary to produce the snow.

One of the most interesting features of this snow which falls to the lee of the Great Lakes due to passage of air across the lake, as compared with snow which falls from higher levels in cyclonic disturbances, is its comparative lesser density. Whereas the usual ratio of snow depth to water equivalent in the latter type of snow is 10 to 1, that for the type of snow which fell in this storm which occurred east of Lake Ontario is likely to be 30 to 1 [2]. Snow as light and fluffy as this, wherein it would take 30 inches of snow to make 1 inch of water is, according to Lansing [3], subject to severe blowing and drifting, visibility being at or near zero for hours at a time and on occasion up to 24 hours. Newspaper accounts of this snow as it affected the Pulaski area state that in the earliest phases of Stage 1 the snow was wet and heavy while the last portion was light and fluffy. It is perhaps not too far afield to speculate that the light fluffy snow is snow which has fallen soon after its formation and crystalization and has not had an opportunity to melt, as compared with cyclonic snow which often has had an opportunity to undergo some melting before reaching the ground. This, of course, is not true of cyclonic snows which fall during periods of very low temperature and such snows are also known to be of low density.

Since it appears from the analysis of this storm of January 28–30, 1953, and from the analysis of others previously referred to, that the entire life history of the snow which falls in such copious amounts takes place within a space which is approximately 200 miles in length and considerably narrower in width, this region at the eastern end of Lake Ontario is ideally suited for the establishment of a laboratory for the study of condensation and precipitation processes. It is also possible that the entire life cycle of some of the snowflakes from the time they leave the lake as water vapor thence to be condensed and fall as snow may take place within a very few feet above the lake and land surface. A similar suggestion was made to the authors two years ago by Mr. B. L. Wiggin, Meteorologist in Charge of the Weather Bureau Office in Buffalo, who considered the region around Buffalo suitable for such a laboratory.

In preparation of this article the authors wish to acknowledge not only the assistance they have received from Mr. Wiggin and his staff, but also that received from the Meteorologists in Charge of the Weather Bureau Offices in Rochester, Syracuse, and Oswego, N. Y., namely Messrs. Williams, Keller, and Loveridge. Mr. H. E. Hull of the Watertown Station of the Civil Aeronautics Administration has also been helpful in supplying data for this article, Finally, the authors wish to acknowledge the considerable help received from Mr. Livingston Lansing of Boonville, N. Y., who is continuing his personal interviews with residents in the affected areas at the time this goes to press.

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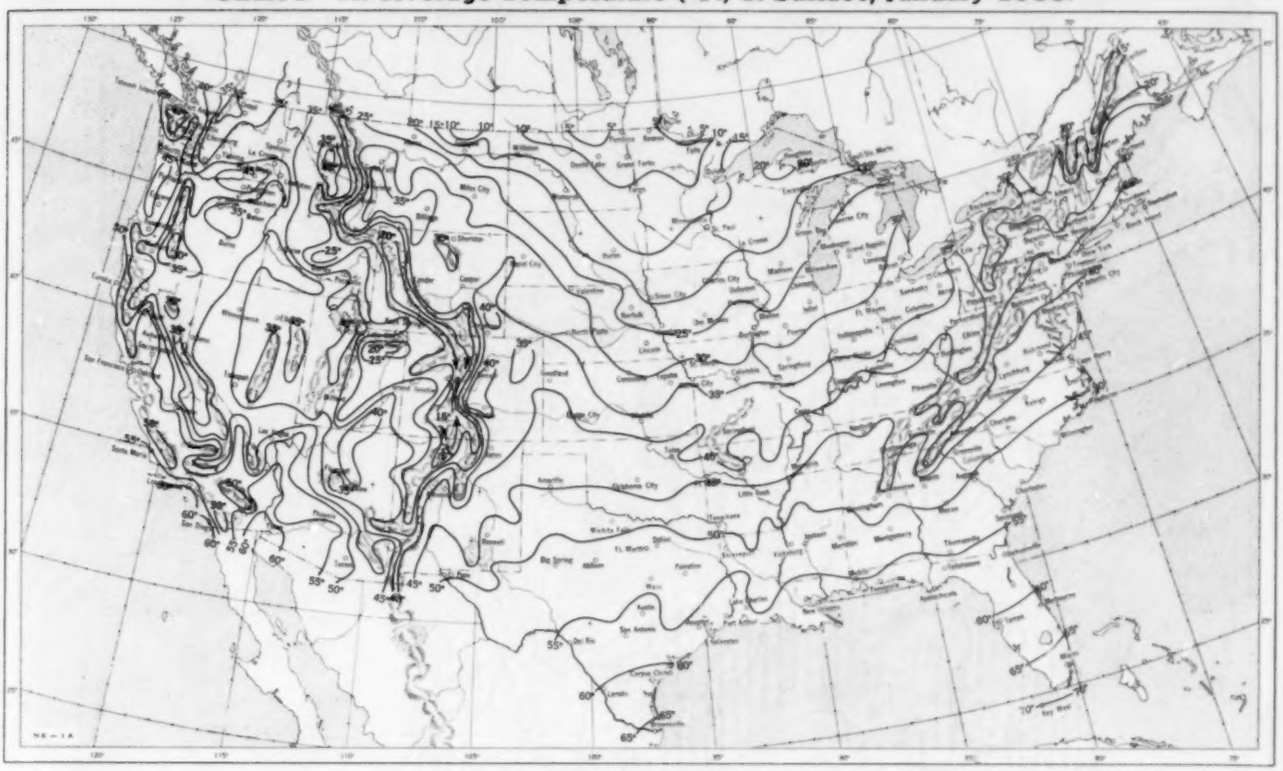
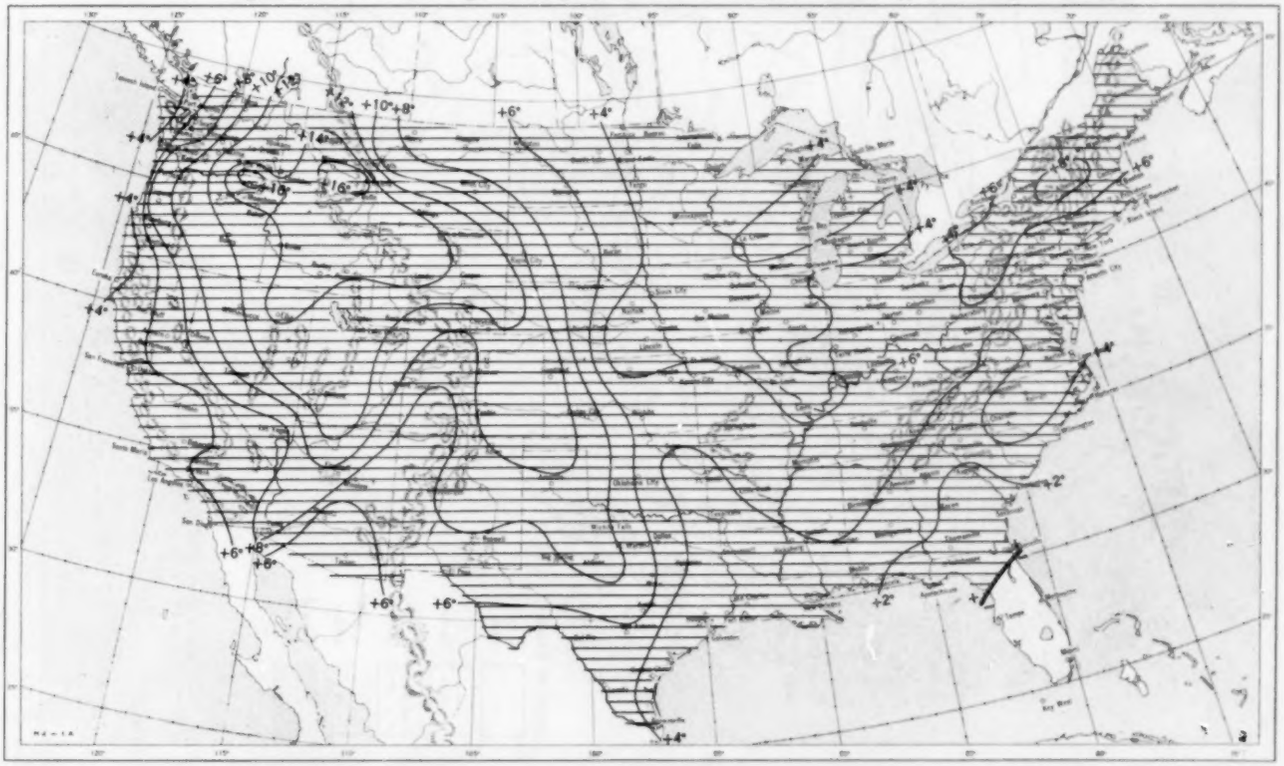
1. B. L. Wiggin, "Great Snows of the Great Lakes," *Weatherwise*, vol. 3, No. 6, December 1950, pp. 123–126.
2. John T. Remick, "The Effect of Lake Erie on the Local Distribution of Precipitation in Winter (I and II)," *Bulletin of the American Meteorological Society*, vol. 23, No. 1, pp. 1–4, No. 3, pp. 111–117, 1942.
3. Livingston Lansing, "Meteorological Characteristics of Snowfall in the Tug Hill, New York Area," paper presented at the Eastern Snow Conference, 1951, Lake Placid, N. Y., February 15, 1951.

Chart I. A. Average Temperature (°F.) at Surface, January 1953.

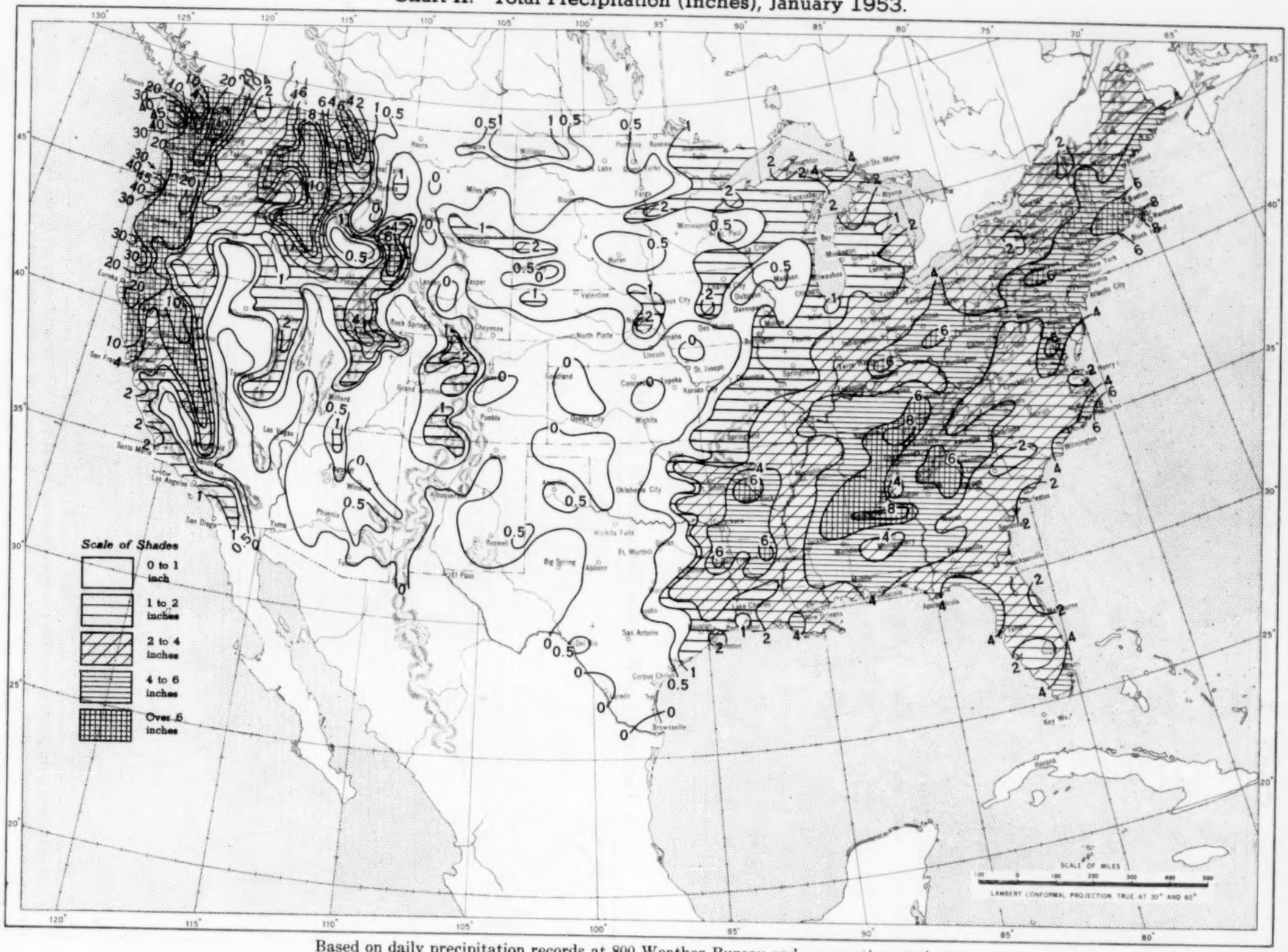


B. Departure of Average Temperature from Normal (°F.), January 1953.



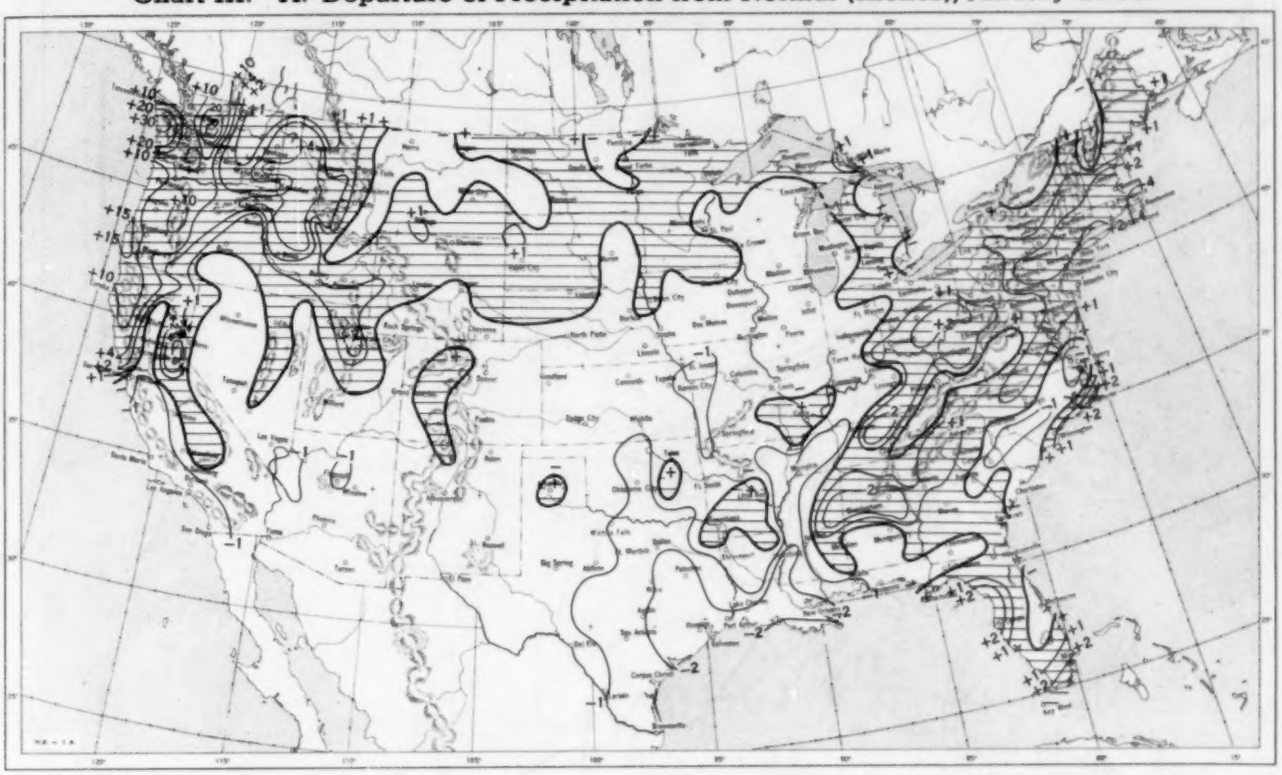
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), January 1953.

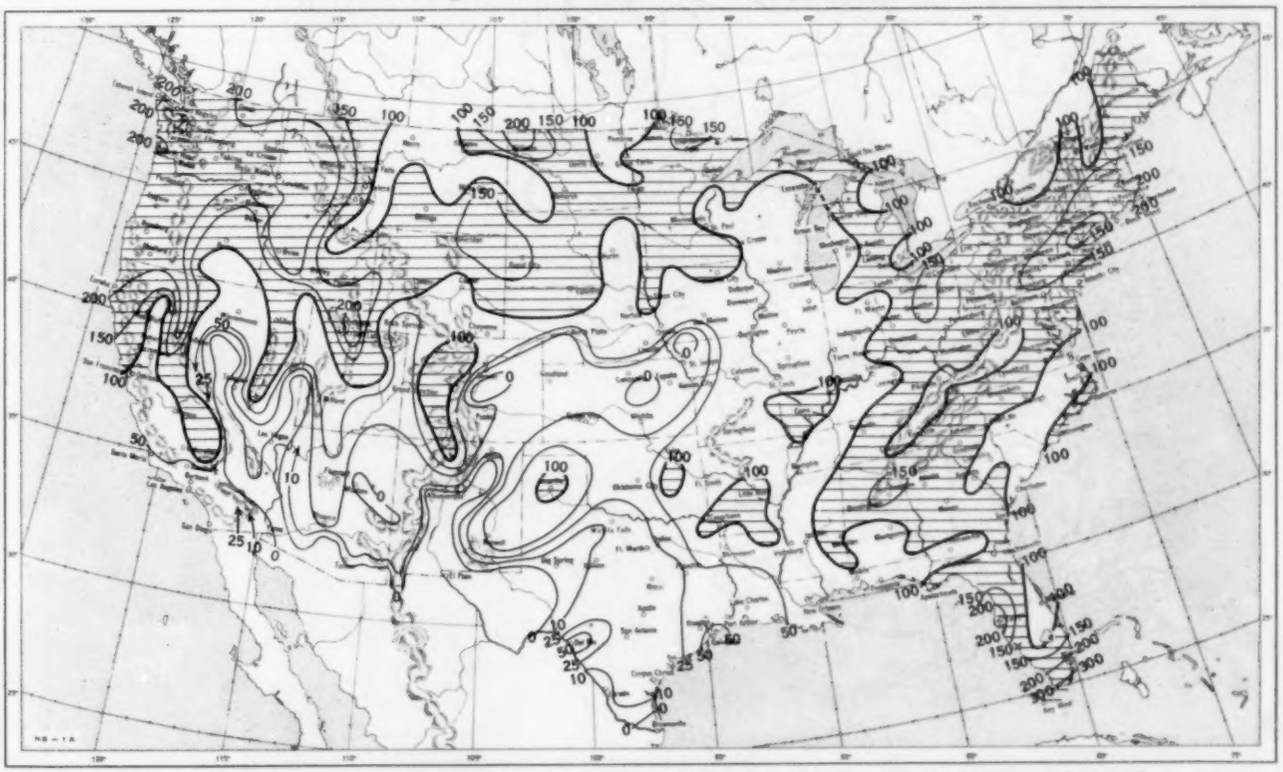

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), January 1953.

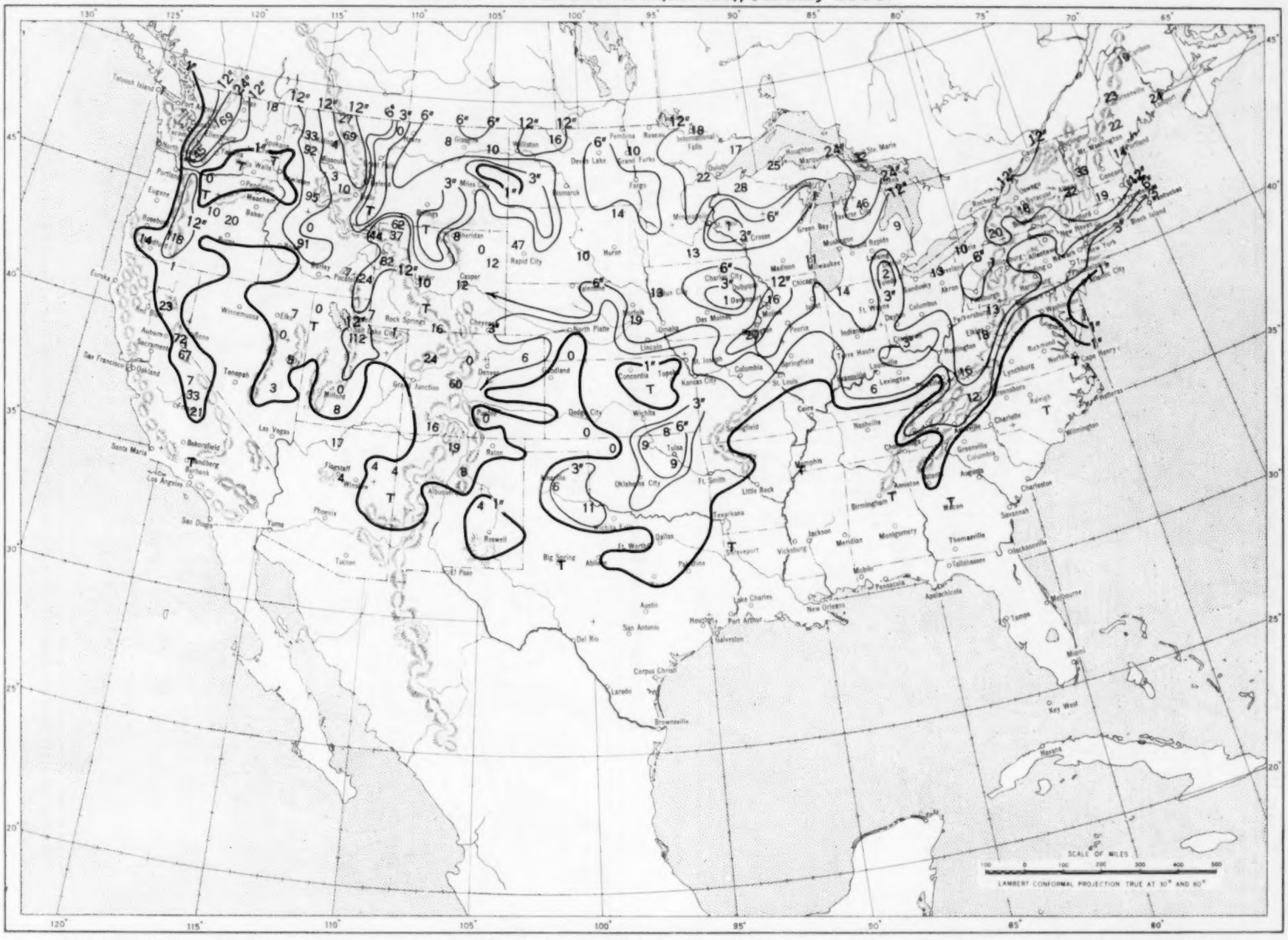


B. Percentage of Normal Precipitation, January 1953.



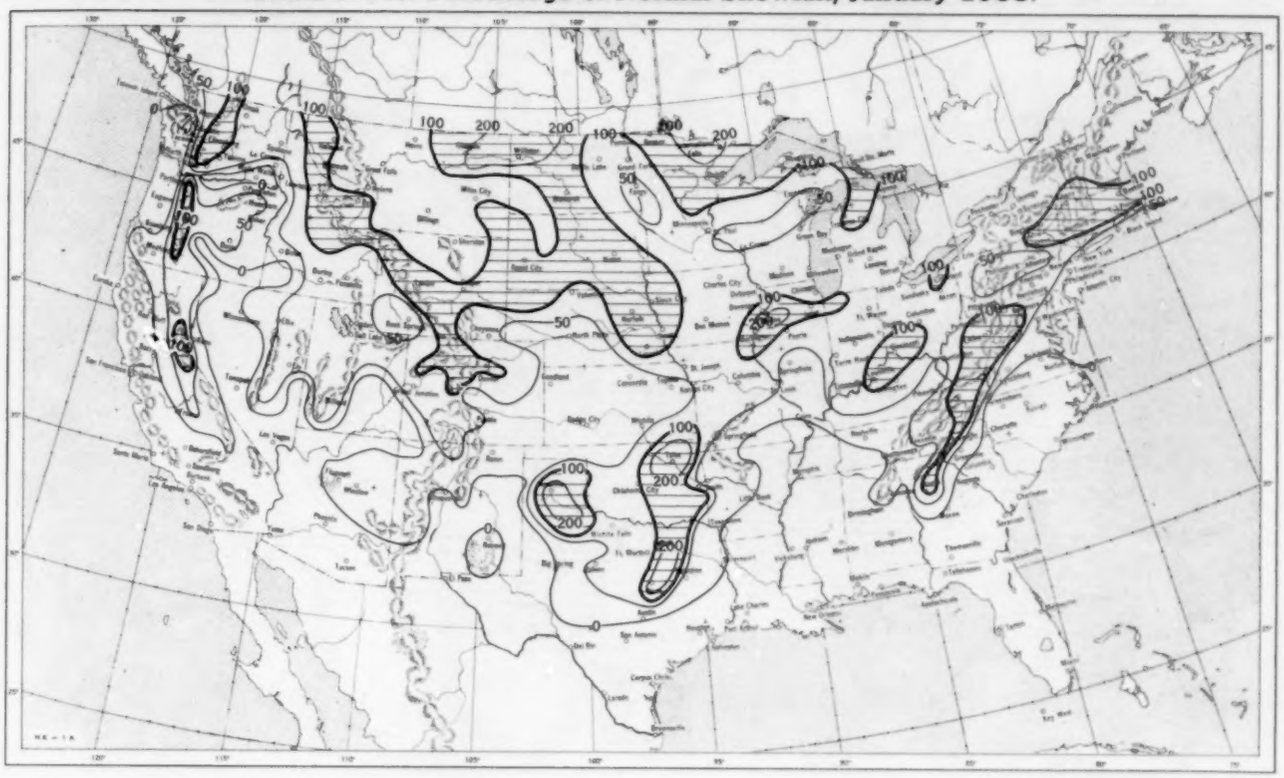
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), January 1953.

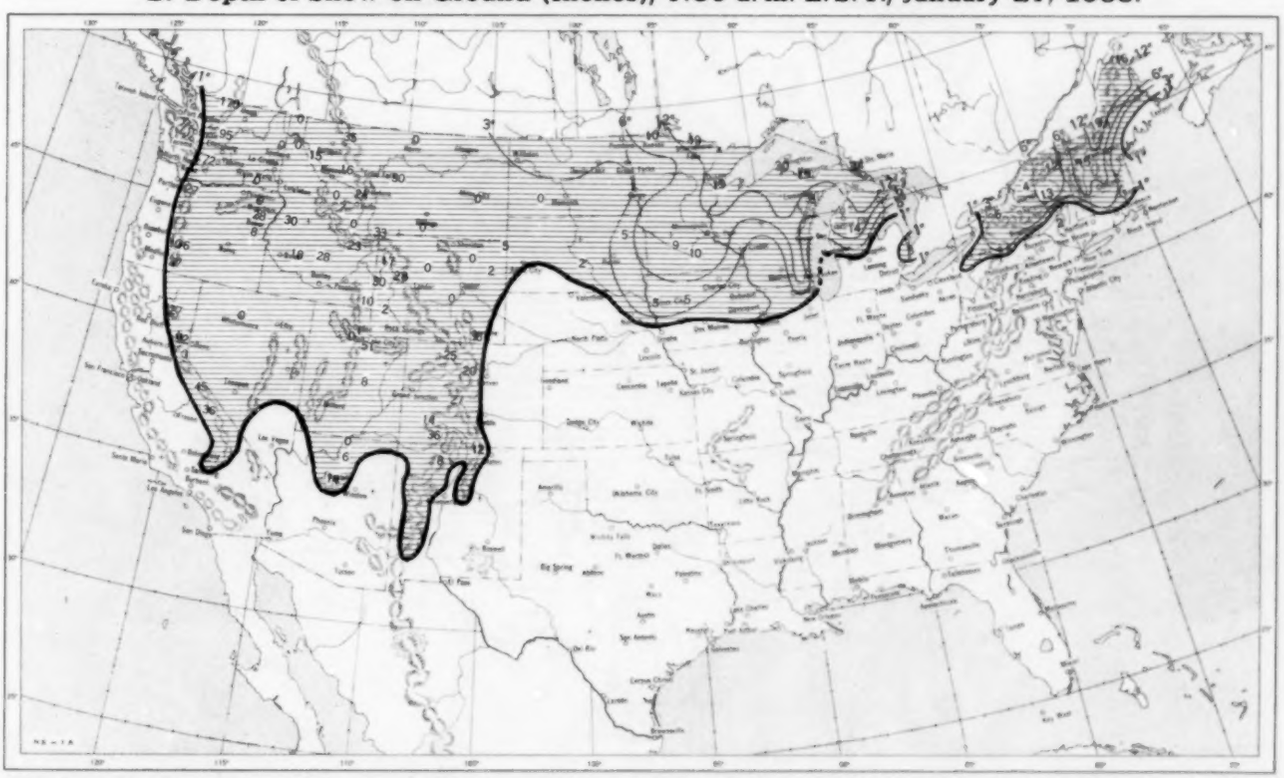


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, January 1953.

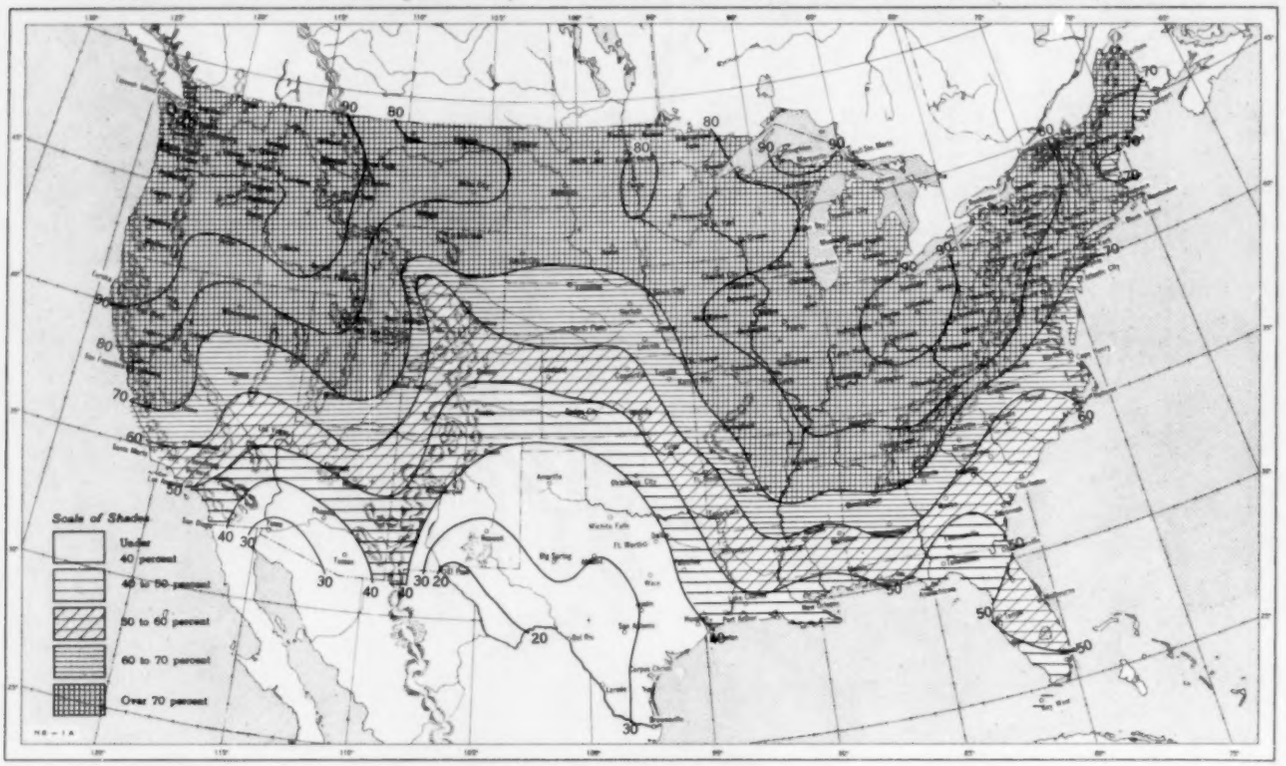


B. Depth of Snow on Ground (Inches), 7:30 a. m. E.S.T., January 27, 1953.

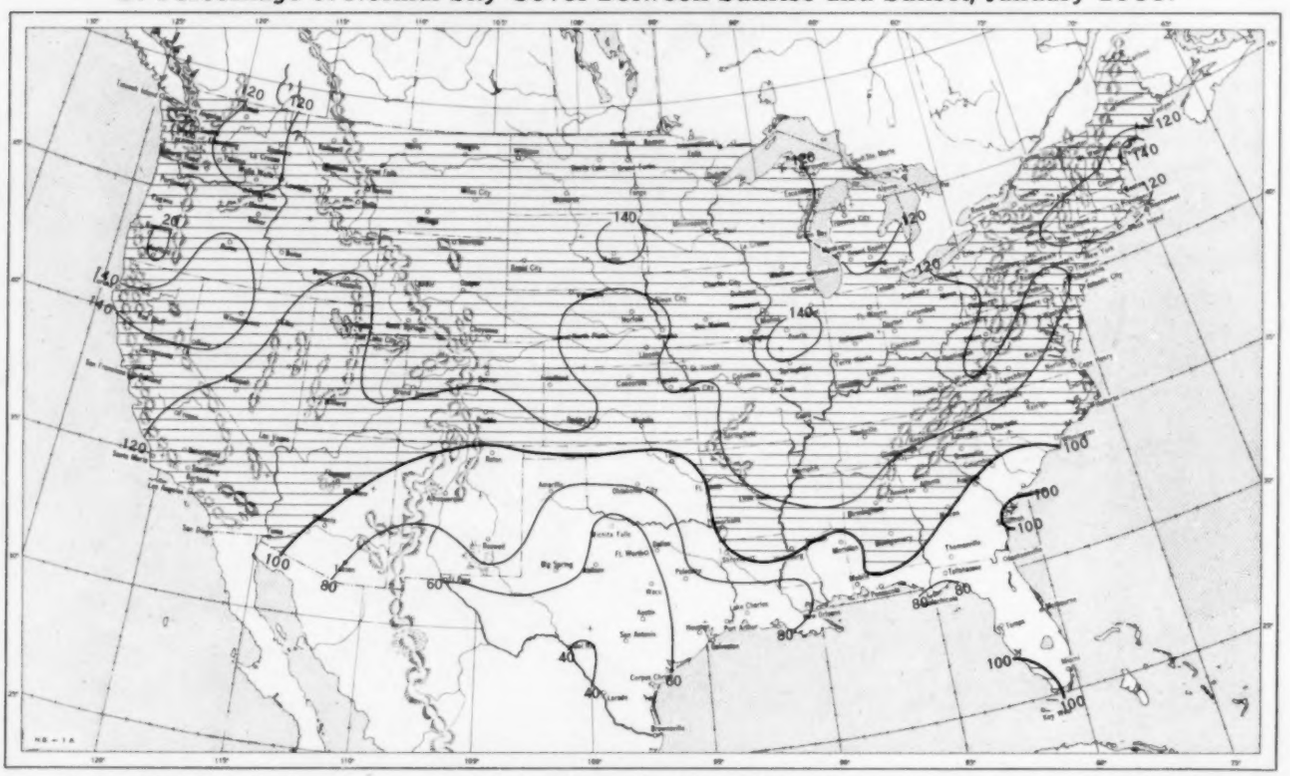


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record. B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, January 1953.

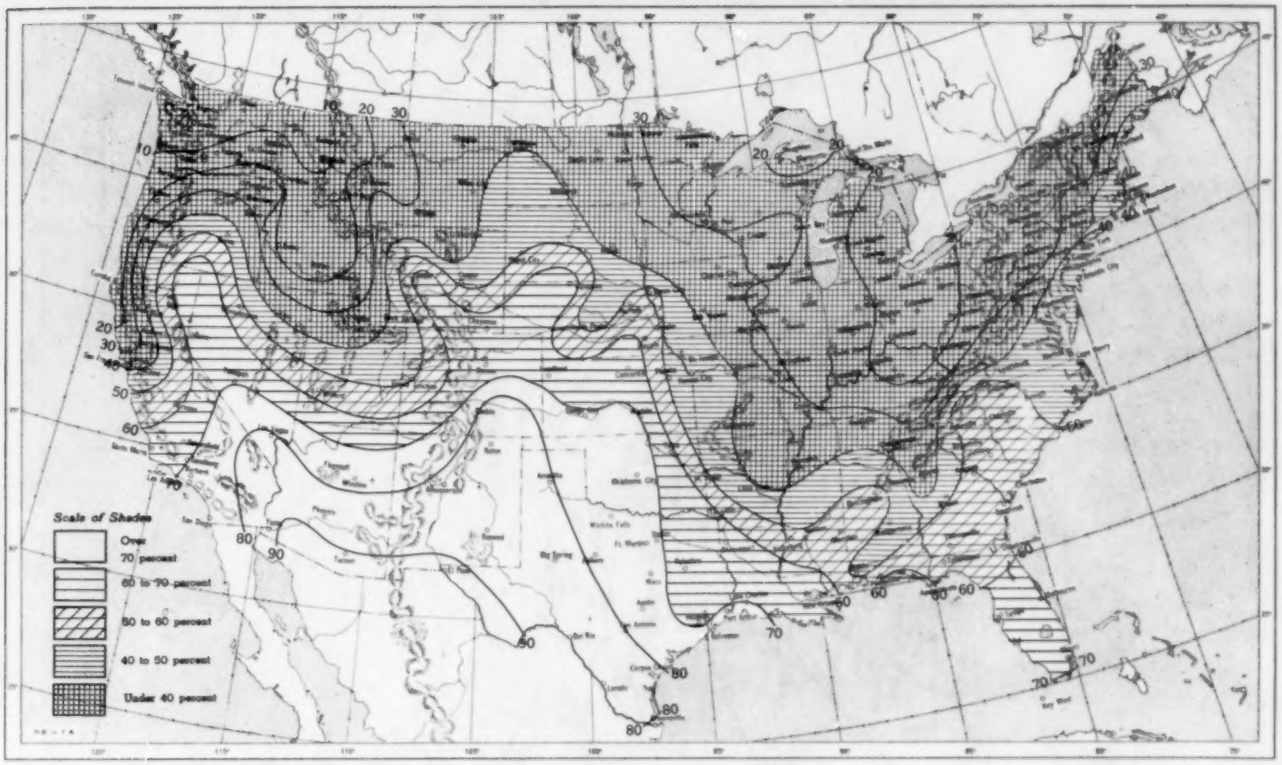


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, January 1953.

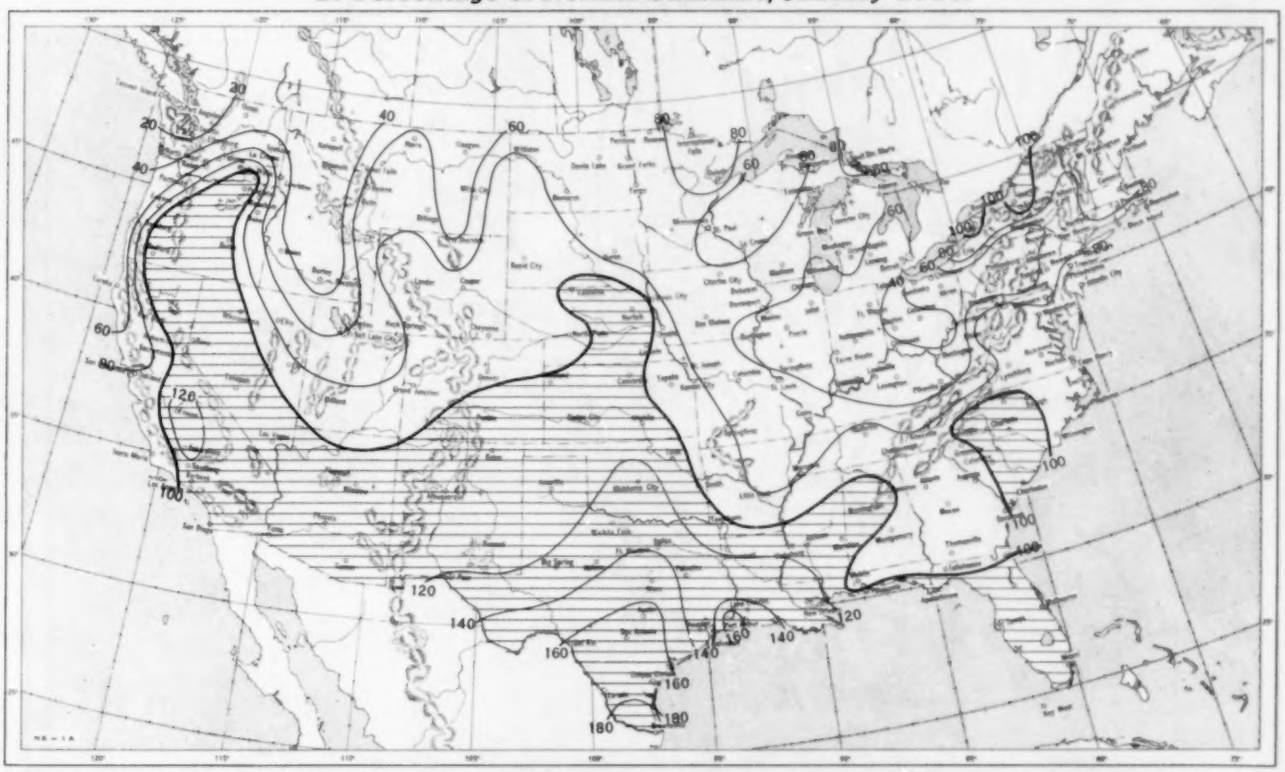


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, January 1953.



B. Percentage of Normal Sunshine, January 1953.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, January 1953. Inset: Percentage of Normal Average Daily Solar Radiation, January 1953.

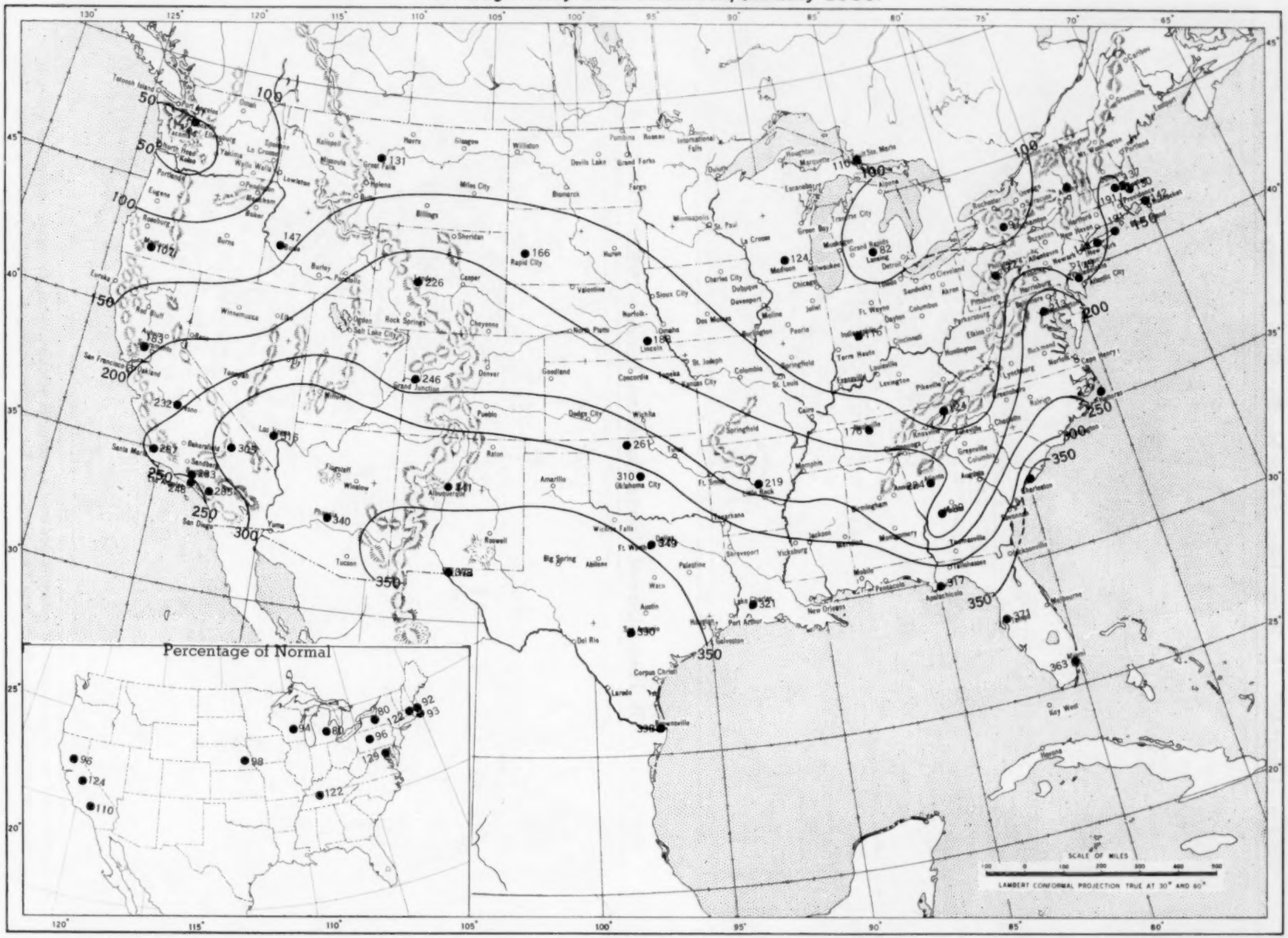
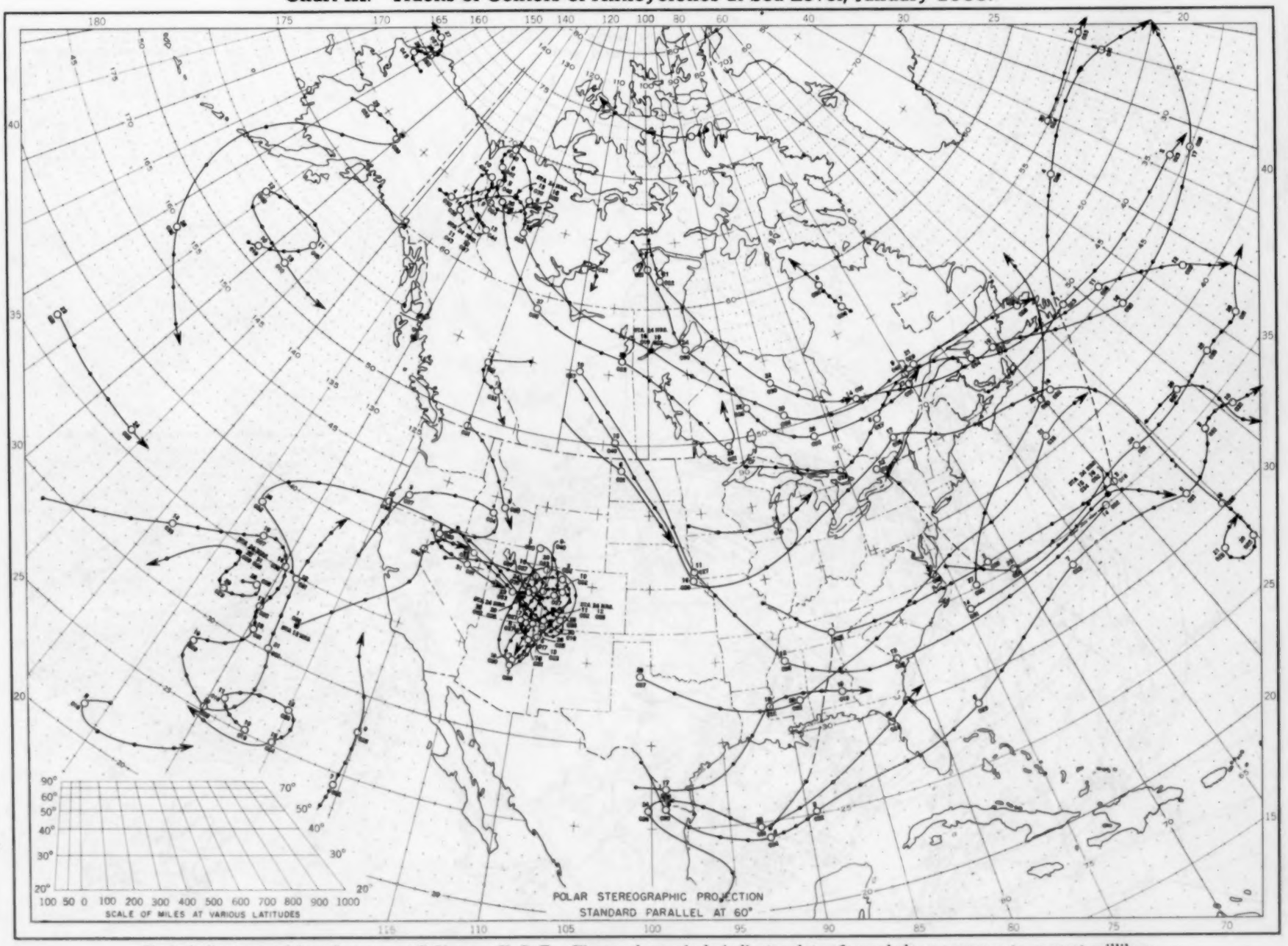


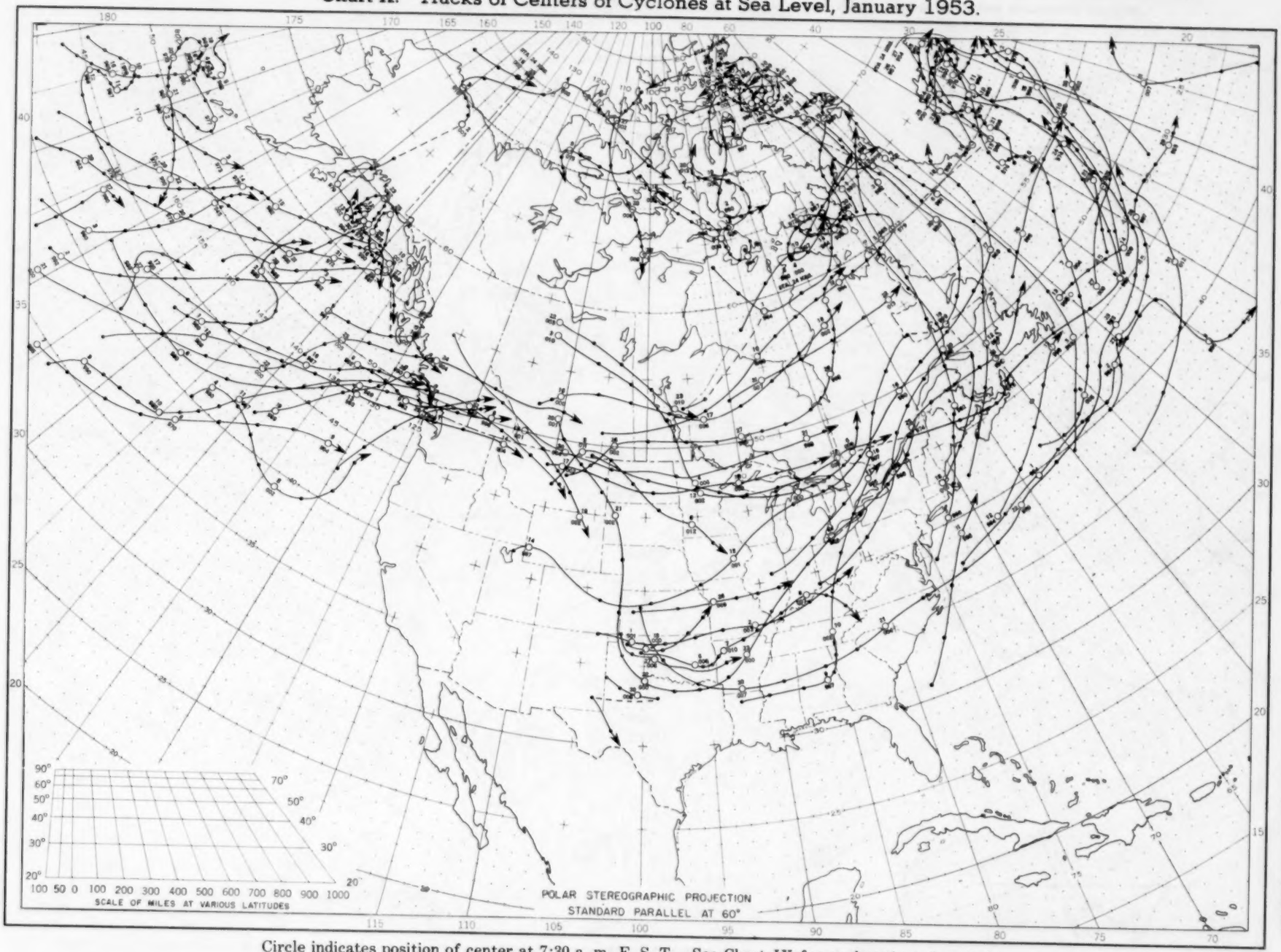
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, January 1953.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

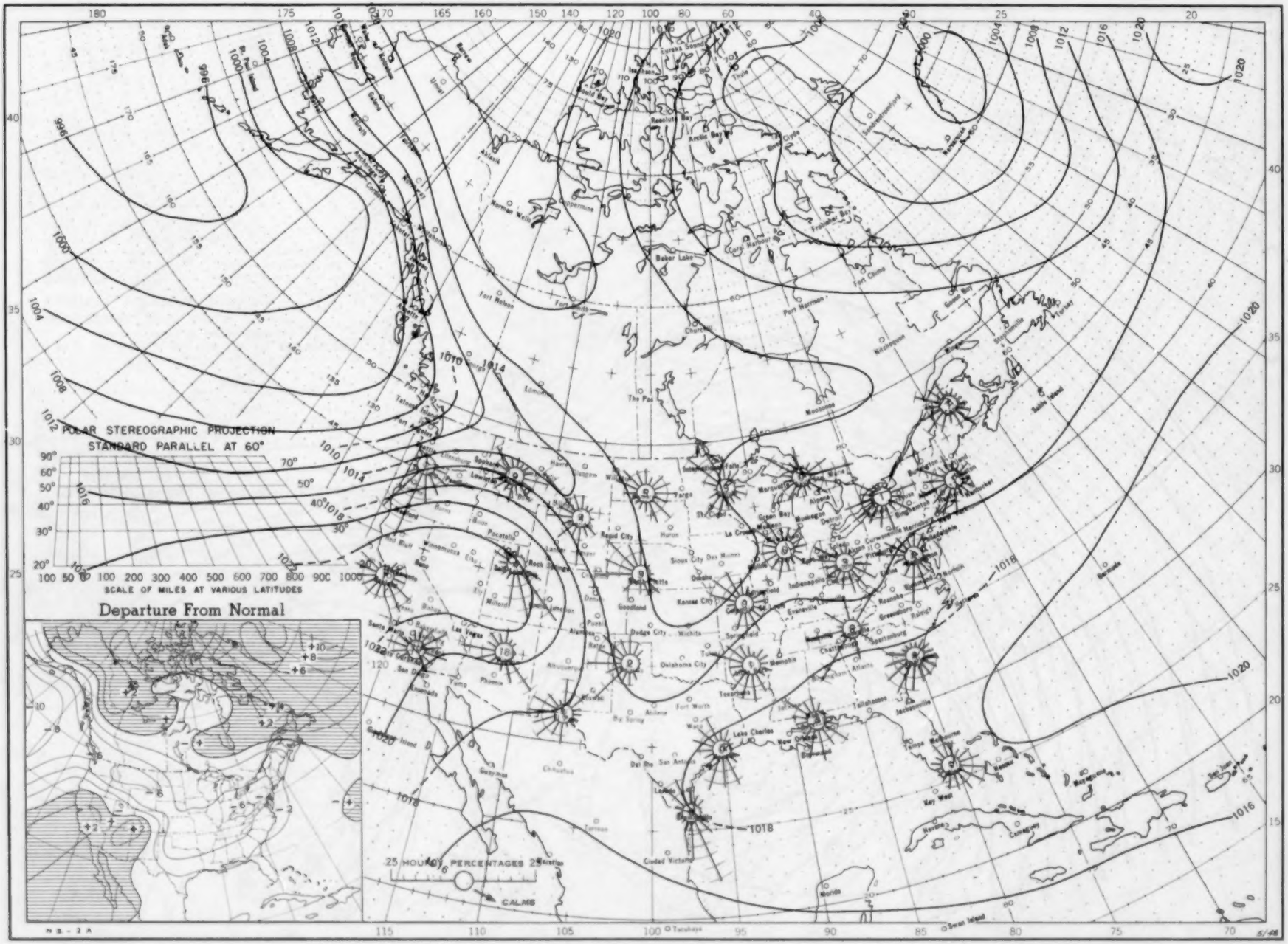
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, January 1953.


SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000
POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°

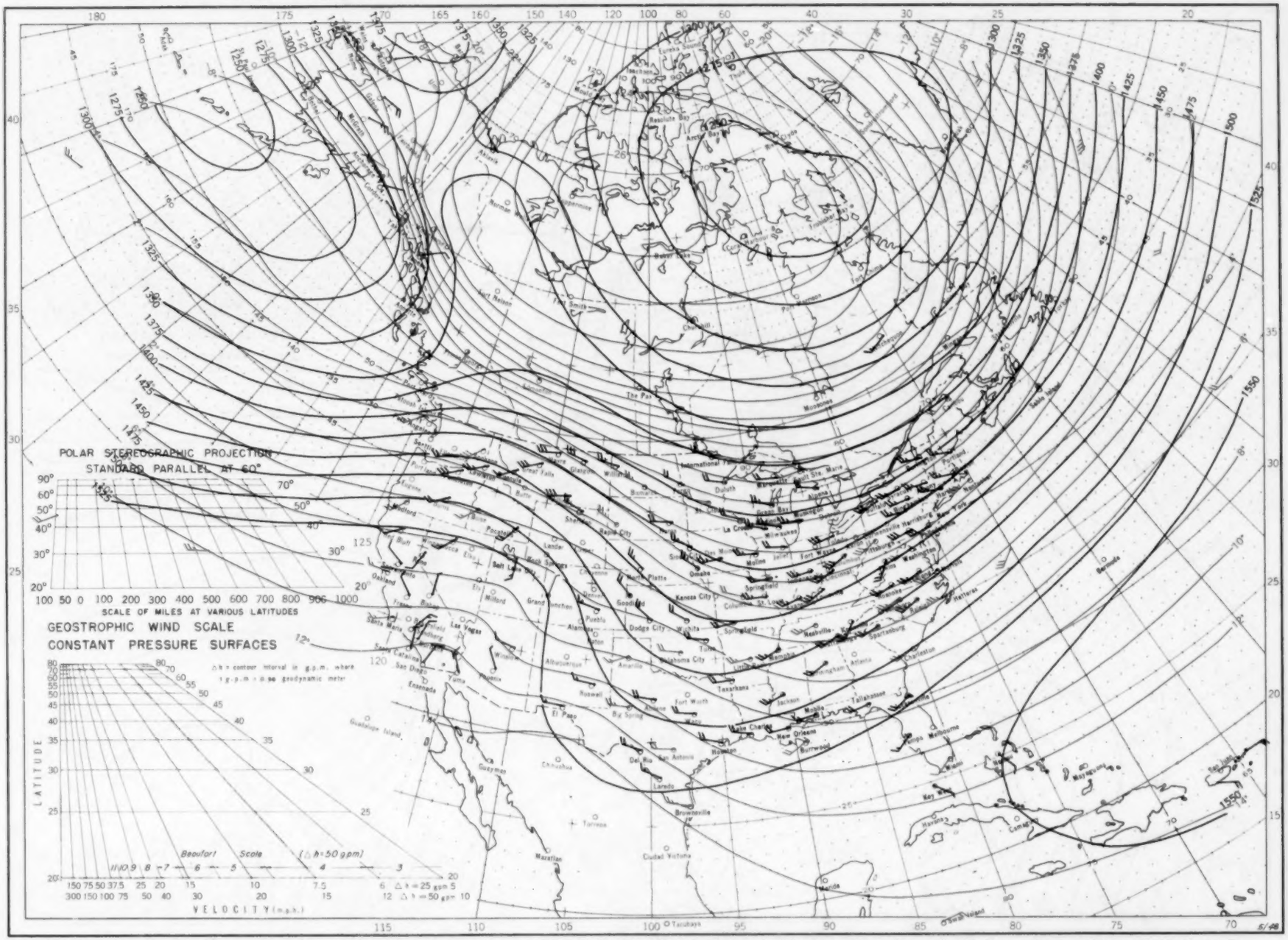
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, January 1953. Inset: Departure of Average Pressure (mb.) from Normal, January 1953.



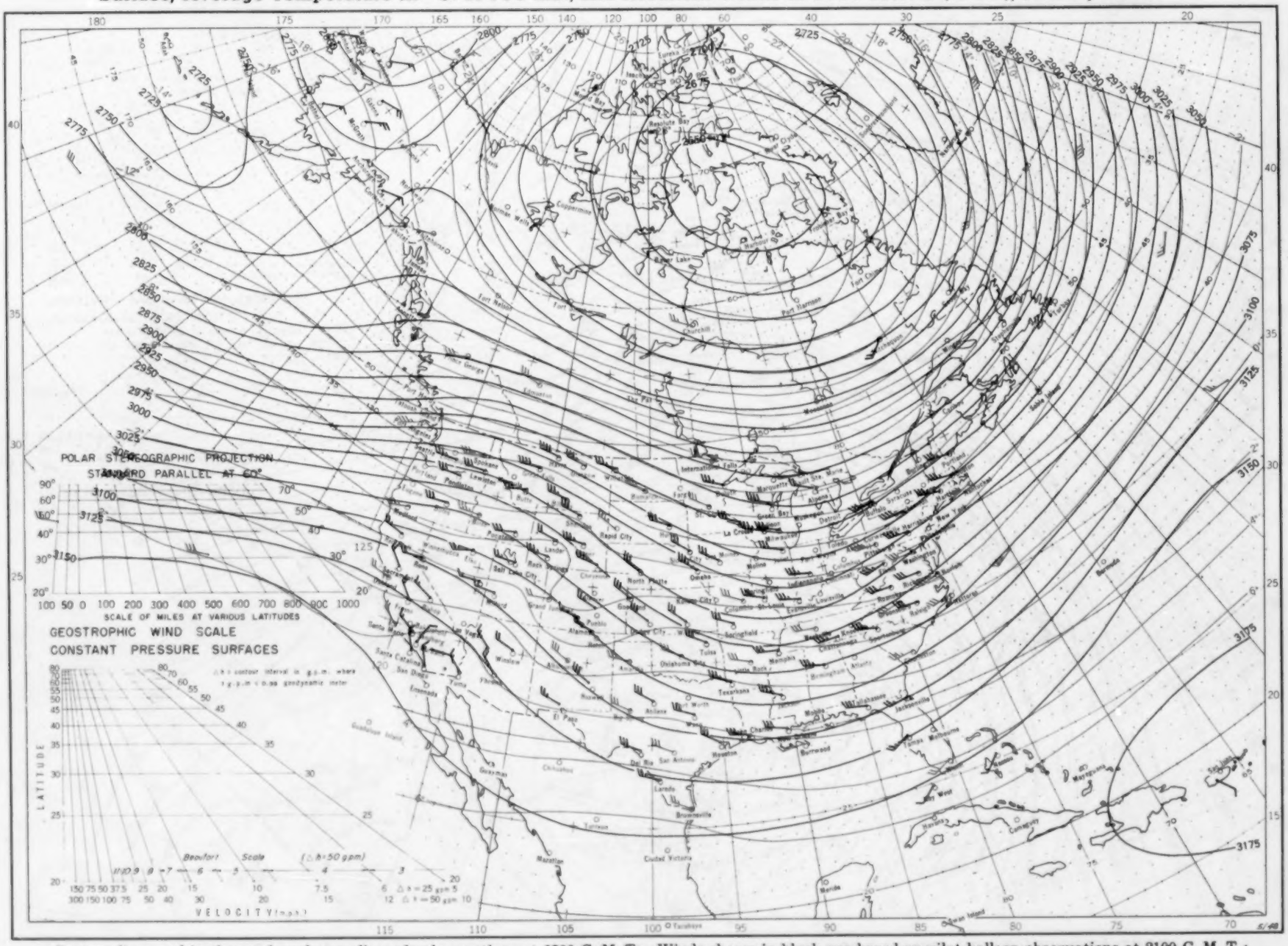
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), January 1953.



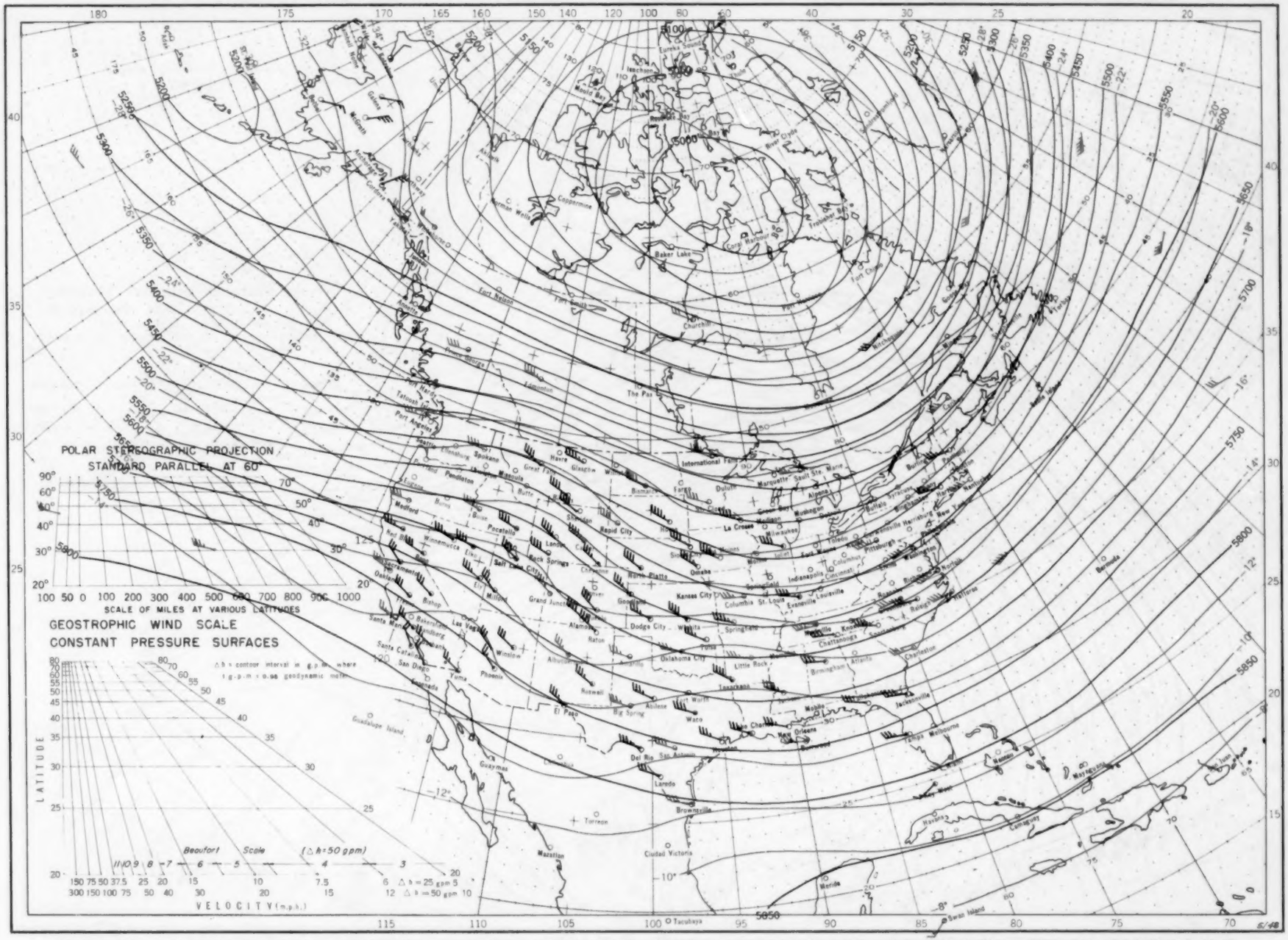
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), January 1953.



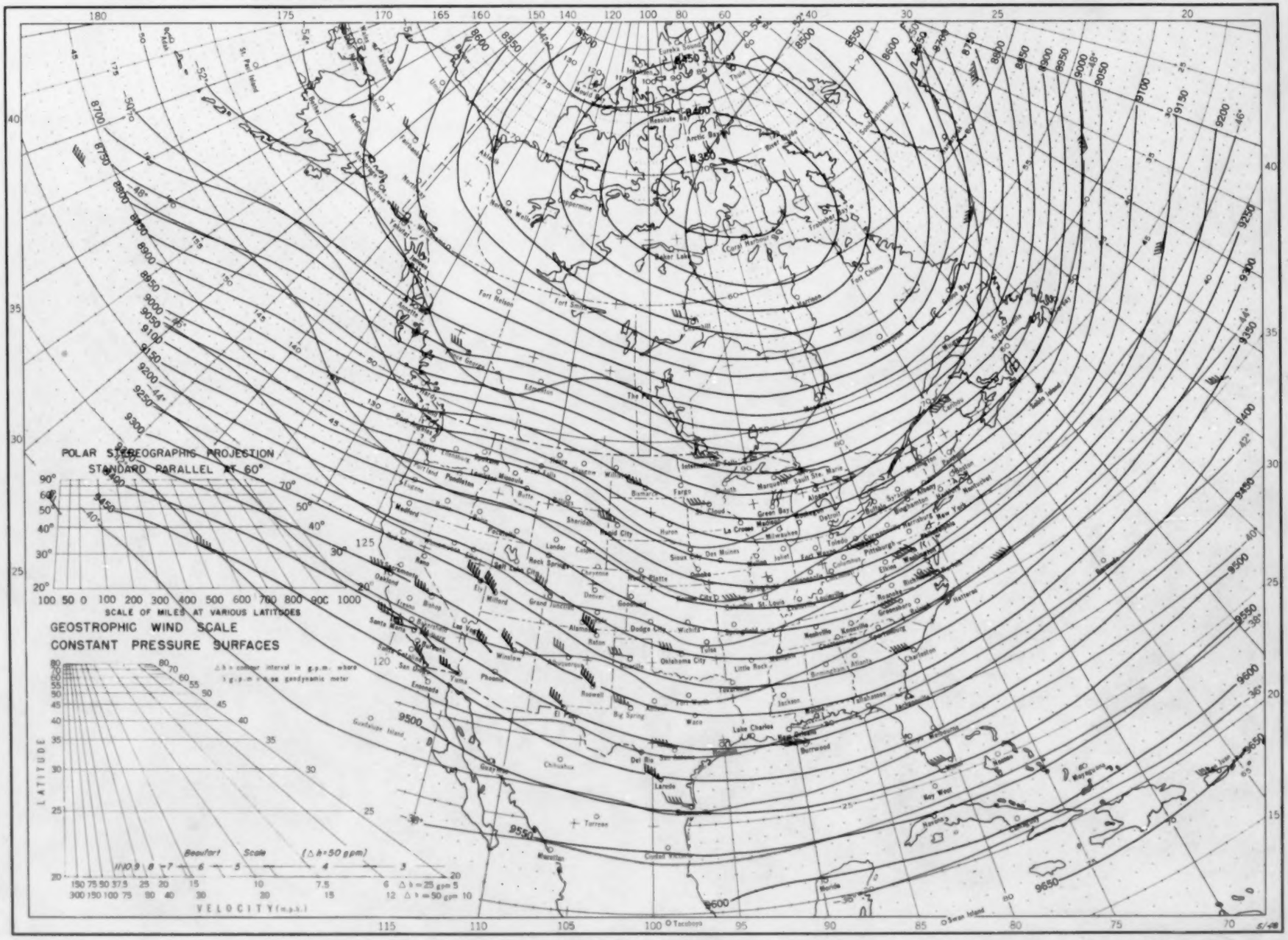
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), January 1953.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), January 1953.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.